Effects of fluctuating lake levels and habitat enhancement on black stilts (*Himantopus novaezelandiae* Gould, 1841)

A thesis
submitted in fulfilment
of the requirements for the

Degree
of
Doctor of Philosophy

by

Mark D. Sanders

University of Canterbury

1996

Contents in brief

Contents

PART TWO: HABITAT ENHANCEMENT

List of tables

List of figures

Abstract

Two questions relating to the conservation of black stilts (*Himantopus novaezelandiae*) were addressed: First, what effects do changes in lake levels have on black stilts? Second, how can habitat be manipulated to enhance food supplies for black stilts? Relationships between lake levels and black stilt food supplies, foraging behaviour, habitat suitability and abundance, on 4 - 6 lake deltas, were investigated. On two deltas, declining water levels exposed abundant food supplies and large expanses of suitable habitat, and attracted more stilts to the deltas than were usually present. On the other deltas, availability of food either decreased or did not change, and amount of suitable habitat increased as lake levels declined. Numbers of stilts using these deltas were not related to lake levels. A specific management question was: what effects would extending the operating range of Lake Pukaki, to include water between 513 and 518 metres above sea level (m a.s.l.), have on black stilts? My results suggest that food supplies and physical habitat are similar above and below 518 m a.s.l., and that extending the operating range would have little or no effect on black stilts.

The influence of site, substratum addition (straw, stones or topsoil), time, and construction method (excavation or inundation) on black stilt food supplies were investigated in three field experiments. Invertebrate biomass and community composition in recently created wetlands (3 months old) appeared to depend primarily on site-specific conditions such as particle size composition and availability of particulate organic material, but could be influenced by substratum additions and construction methods. Captive black stilt chicks were able to capture and consume common prey taxa that were present on experimental substrata. Wild black stilts foraged and nested at some of the experimental wetlands. These results suggest that wetland enhancement has excellent potential as a management technique for black stilts.

Executive summary

The black stilt (*Himantopus novaezelandiae* Gould, 1841) is one of New Zealand's most endangered birds (Bell 1986; Molloy *et al.* 1994), and is possibly the world's rarest wading bird (Hayman *et al.* 1986). Black stilts were once widespread throughout most of New Zealand, but are now almost entirely restricted to the Upper Waitaki River Basin, where they inhabit braided riverbeds, lake deltas, ponds, swamps and tarns (Pierce 1982a, 1984a). The reduction in numbers and range of black stilts resulted primarily from predation by introduced mammals, combined with and exacerbated by loss and degradation of habitat (Pierce 1984a, 1986a). Aims of current black stilt management include the preservation and enhancement of black stilt habitat (Reed *et al.* 1993a).

In this thesis I address two broad questions relating to the conservation and management of habitat for black stilts. First, what affects - if any - do changes in lake levels have on black stilts? Second, how can habitat be manipulated to enhance food supplies for black stilts? I addressed the first question by investigating the relationships between lake levels and black stilt food supplies, foraging behaviour, habitat availability, and habitat use (Chapters 2 - 5). To address the second question, I conducted three substratum manipulation experiments in the field (Chapters 7 - 9), and a feeding experiment on black stilt chicks in captivity (Chapter 10). I also surveyed food supplies at black stilt nest sites (Chapter 6), and conducted an observational study of the use of newly created wetlands by pied and black stilts (Chapter 11).

My investigation of the effects of lake levels on black stilts was conducted at the six lake deltas of the four large hydro lakes in the Upper Waitaki Basin, in the central South Island. These deltas were the Tasman Delta of Lake Pukaki, the Godley and Cass Deltas of Lake Tekapo, the Hopkins Delta of Lake Ohau, and the Ahuriri and Tekapo/Ohau Deltas of Lake Benmore. For the purposes of this thesis I defined lake deltas as those areas delimited by the sides of the valley at the head of a lake, a line parallel to and 100 m upstream from the maximum control level of the lake, and the lake edge. I included all six deltas in my study because ECNZ's integrated operation of the Upper Waitaki lakes potentially affects all black stilts that overwinter on these lake deltas. This broad study was motivated by a more specific management question, namely, "what are the likely effects on black stilts of lowering the legal minimum operating level of Lake Pukaki by five metres, from 518 to 513 m a.s.l?

This specific question arose during the electricity shortage of winter 1992, when the Electricity Corporation of New Zealand (ECNZ) applied for, and was granted, special permission to use an extra five metres of water from Lake Pukaki. A major concern expressed at the time by the public (James 1992; various letters to the editor in daily newspapers, late 1992), the Department of Conservation, (Hughey 1992; Murray 1992, 1993) and Conservation organisations (*e.g.* Anon. 1992), was that operating Lake Pukaki below 518 m a.s.l. might cause a shortage of food supplies for black stilts that were overwintering on the Tasman Delta of Lake Pukaki. Another concern was that, below 518 m a.s.l., parts of the Tasman Delta might be physically unsuitable for black stilts because of the formation of steep banks at the lake edge (Murray 1992).

Ultimately, ECNZ did not need to draw Lake Pukaki below 518 m a.s.l. during the 1992 electricity shortage (the minimum level in 1992 was 518.92 m a.s.l.), and black stilts were not subjected to any putative effects of extending its operating range. Nevertheless, the question regarding the effects of drawing Lake Pukaki below 518 m a.s.l. remains relevant because ECNZ is likely to reapply for access to the 'extra five metres' of water in Lake Pukaki. The water represents up to 300 GWh of storage that is available at almost nil cost to ECNZ, at a time when New Zealand's demand for electricity, and the marginal cost of electricity production is increasing (R. Sutton, Southpower, pers. comm.). That ECNZ was in the process of applying for access to this water through conventional channels, prior to the electricity shortage (Davison *et al.* 1992), demonstrates that ECNZ's desire for access to the water in Lake Pukaki was not restricted to 1992.

Because Lake Pukaki has not been drawn below 518 m a.s.l. since it was raised in 1978 (Martin 1991), predictions about the likely effects of extending the operating range must be based upon data collected within the current operating range (518 - 532 or 532.5 m a.s.l.). Reliable predictions can be made regarding the availability of food on the Tasman Delta when Lake Pukaki is below 518 m a.s.l. Food for black stilts was extremely scarce within the lower six metres of the current operating range (*i.e.* 518 - 524 m a.s.l.), undoubtedly because the fine, inorganic substrata (silt and fine sand; this thesis Appendix 1; Irwin 1972), low temperature, silt-laden water, and the ultra-oligotrophic status of Lake Pukaki (Livingston *et al.* 1986) provide an unsuitable environment for most aquatic macro-invertebrates (Ward 1992). It seems likely that the little food that was available at the lake edge of the Tasman Delta, between 518 and *c.* 524 m a.s.l., comprised not the resident benthos, but invertebrates that had been carried into the lake by streams. Below 518 m a.s.l., food is also likely to be scarce at the lake edge, but invertebrates would probably continue to drift into the lake and be deposited in the littoral zone. The scarcity of food between 518 m a.s.l. and *c.* 524 m a.s.l. was reflected in a tendency for black stilts to

feed there at slower rates than at higher lake levels. It is likely that if the level of Lake Pukaki fell below 518 m a.s.l., feeding rates would be similar to those between 518 and 524 m a.s.l. That is, they would be highly variable, but relatively low on average.

The type of physical habitat that would be available on the Tasman Delta if the level of Lake Pukaki fell below 518 m a.s.l. is also predictable: the delta will provide increasingly large expanses of open, unvegetated habitat as the lake declines. Approximately 5 km^2 of such habitat is available between 518 and 532 m a.s.l. This habitat will still be available to black stilts, regardless of what happens to the lake below 518 m a.s.l. However, the physical nature of the habitat at the lake edge may change as the level of Lake Pukaki declines and finer substrata are exposed. The fine substrata of the Upper Waitaki Lakes are prone to erosion (Mark and Kirk 1987; Mark 1987), and at low lake levels the lake edge of the Tasman Delta may be unsuitable for black stilts because of the presence of steep banks.

In the long term, the best indicator of the value of the Tasman Delta as black stilt habitat is probably the number of black stilts that choose to use the delta. In Chapter 4, I showed that numbers of black stilts sighted on the Tasman Delta during the winters of 1984 - 1994 were highly variable and unrelated to lake level. This suggests that lake level does not strongly influence black stilts on the Tasman Delta, at least within the range of levels I investigated. On the basis of field observations, I consider that the number of black stilts on the Tasman Delta is influenced much more strongly by weather-related factors such as floods, ice formation (on the deltas and elsewhere), wind, and wave size than by lake levels. Nevertheless, I recommend that any extension of the legal operating range of Lake Pukaki is accompanied by ongoing monitoring of the responses of black stilts. Such monitoring should focus on the numbers of black stilts that use the Tasman Delta, and ultimately on their survival and breeding success.

In contrast to the situation at Lake Pukaki, declines in the level of Lake Benmore were associated with dramatic increases in the numbers of black stilts (*e.g.* increases from 0 to 21) and in the availability of habitat and food supplies on the Ahuriri Delta, and also with increases in numbers of black stilts and availability of habitat on the Tekapo/Ohau Delta. In the light of these potentially beneficial effects, one option for the management of black stilts would be to intentionally lower Lake Benmore at appropriate times of year. Lowering Lake Benmore may benefit black stilts in at least four ways: 1) opportunities for unpaired black stilts to find mates may be increased, 2) exposing abundant food supplies could improve the breeding condition of black stilts, 3) drawdowns could be used to provide alternative habitat for black stilts if other habitats were unavailable, and 4) a drawdown coinciding with a release of captive-reared black

stilts on the Tekapo/Ohau Delta (or possibly the Ahuriri Delta) may increase the chances of survival of the birds by providing an abundant and accessible food supply, and by encouraging them to stay on the relatively safe delta. It must be emphasized that these benefits are currently speculative. An evaluation of drawdowns as a management tool would need to investigate whether the putative benefits are real.

Unlike Lakes Pukaki and Benmore, changes in the levels of Lakes Tekapo and Ohau did not strongly affect any aspects of the ecology of black stilts on the Godley, Cass or Hopkins Deltas. Numbers of black stilts on the Cass Delta decreased slightly as the level of Lake Tekapo declined, but total numbers of black stilts on Lake Tekapo (*i.e.* on the Godley and Cass Deltas combined) were not related to lake level. Few black stilts used the Hopkins Delta, perhaps because it provided only a small area of unvegetated, flat habitat. The low numbers of black stilts, and small area of black stilt habitat on the Hopkins Delta, suggest that lakes that vary little in level may provide poor habitat for black stilts. However, a powerful test of this hypothesis would require a larger sample of lake deltas than is available in the Upper Waitaki Basin.

In Part II of this thesis, I demonstrated that constructed or manipulated wetlands can provide abundant and suitable food supplies for black stilts. An initial small-scale field experiment (Chapter 7) showed that adding various substrata to wetlands could strongly influence invertebrate community composition and standing crop. Two large-scale field experiments (Chapters 8 and 9) demonstrated that substratum additions, construction methods and 'site' interacted to influence the type and amount of food present in constructed wetlands. Generally, invertebrate community composition and standing crop appeared to be influenced most strongly by local, site-specific factors such as particle size composition and organic matter content of the substratum. However, at some sites, substratum additions and construction methods strongly influenced aquatic invertebrate communities. Therefore, to provide the most suitable foraging habitat for black stilts, managers need to carefully consider the likely effects of 'site', substratum additions and construction methods.

In the field experiment reported in Chapter 8, invertebrate community composition and biomass in 10 m diameter ponds were measured 3 and 15 months after pond construction. One general pattern emerged from this experiment; regardless of substratum manipulations, invertebrate communities at any particular site showed a tendency to converge over time, in taxonomic composition and relative biomass of different food types. Thus, communities became more saturated with species, and chironomid biomass tended to decline, while oligochaete and mollusc biomass increased as ponds aged. The biomass of 'nektonic' invertebrates tended to increase

over the first year or two, and then decline. If larval Chironomidae and nektonic invertebrates are the most attractive foods for black stilts, as suggested by my field observations (Chapters 3, 11), wetlands in early stages of succession should provide the most suitable food supplies for them. 'Resetting' wetlands by physically disturbing them, or by manipulating water levels, may ensure that they continue to provide appropriate food supplies for black stilts.

Field experiments reported in Chapters 7 and 8 demonstrated that wetlands constructed in winter (August) could provide abundant food resources within three months, and would sometimes be used by black (and pied) stilts immediately (Chapter 11). The range of invertebrate biomass in the experimental wetlands was similar to that at black stilt nest sites (Chapter 6). However, if managers choose the most suitable sites and substrata, constructed wetlands should provide more abundant food supplies than most natural nest sites.

CHAPTER 1

General introduction

The black stilt (*Himantopus novaezelandiae* Gould, 1841; Fig. 1.1) is one of New Zealand's most endangered birds (Bell 1986; Molloy *et al.* 1994), and is possibly the world's rarest wading bird (Hayman *et al.* 1986). Black stilts were once widespread throughout most of New Zealand, but are now almost entirely restricted to the Upper Waitaki River Basin (Fig. 1.2), where they inhabit braided riverbeds, lake deltas, ponds, swamps and tarns (Pierce 1982a, 1984a). The reduction in numbers and range of black stilts resulted primarily from predation by introduced mammals, combined with and exacerbated by loss and degradation of habitat (Pierce 1984a, 1986a). Aims of current black stilt management include the reduction of predation on black stilt eggs and chicks and the preservation and enhancement of black stilt habitat (Reed *et al.* 1993a). In this thesis I report the results of research concerning two current management questions relating to the conservation of black stilt habitat.

The first question relates to putative effects on black stilts of changes in lake levels caused by hydroelectric power (HEP) generation. This question arose as part of public debate during an electricity shortage in winter 1992. The second question relates to a habitat enhancement programme that is being undertaken by the New Zealand Department of Conservation's Project River Recovery (PRR). In cooperation with PRR I investigated ways to enhance black stilt food supplies in wetlands.

In this chapter, I provide a summary of the ecology of black stilts, the decline and current status of the species, and the current focus of black stilt management and research. I then outline how the HEP generation system works in New Zealand, and describe how I have addressed the questions that arose during the 1992 electricity shortage. Finally, I describe the rationale for PRR's habitat enhancement work, and outline the approaches that I have taken to several questions related to habitat enhancement for black stilts.

THE BLACK STILT

Taxonomy

The black stilt is endemic to New Zealand and is the most distinctive species of the cosmopolitan genus *Himantopus* (Family: Recurvirostridae, Order: Charadriiformes). It is distinguished morphologically from other stilts by the totally black plumage of the adults, its longer bill, shorter tarsometatarsus, longer wings and greater mass (Gould 1841; Pierce 1984b). Since the species was described by Gould in 1841, much confusion has surrounded its taxonomic status (reviewed by Pierce 1984b). The confusion apparently arose partly because black stilts are interfertile with Australasian pied stilts (*H. h. leucocephalus* Gould, 1837) and adult hybrids have intermediate plumage (Pierce 1984b). Furthermore, juvenile black stilt plumage is similar to hybrid plumage.

Figure 1.1. Adult black stilt (*Himantopus novaezelandiae* Gould, 1841) foraging. Photograph courtesy of Dave Murray.

However, black stilts differ sufficiently from pied stilts in morphology (Pierce 1984b), behaviour (Pierce 1985, 1986a), ecology (Pierce 1982a) and genetics (Green 1988) to retain their specific status (Pierce 1984b; Hayman *et al.* 1986; Turbott 1990). For identification and management purposes, Pierce (1984b) classified hybrids according to the amount of black in their plumage. Plumage classifications range from 'node A' (pure pied) to 'node J' (pure black).

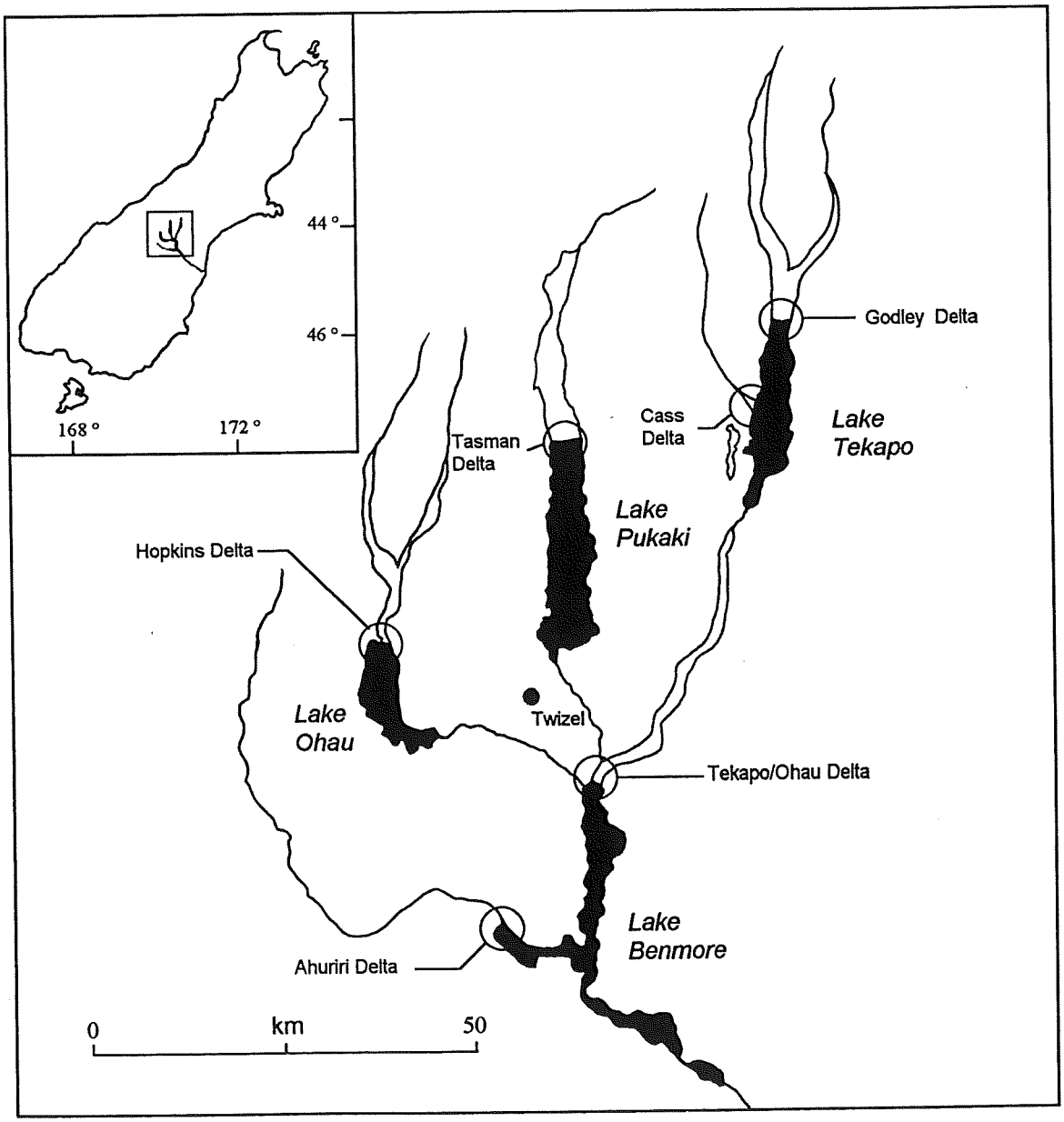


Figure 1.2. Map of the Upper Waitaki River Basin, to which most black stilts are now restricted. The four large Upper Waitaki lakes that the Electricity Corporation of New Zealand use to generate electricity, and the lake deltas on which many black stilt overwinter are shown. The black stilt captive rearing facility is located at Twizel.

It is widely considered that black and pied stilts descended from the same ancestral stock (*e.g.* Soper 1976; Pierce 1984b; Reed *et al.* 1993a; Holdaway 1995). Black stilts apparently evolved in New Zealand following an early invasion from Australia thousands of years ago, while the Australian ancestral stock evolved into the Australasian pied stilt. Pied stilts have only become abundant (*c.* 30 000 in the early 1980s, Pierce 1984a), in New Zealand in the past 100 years and may have invaded from Australia as recently as the early 19th century (Fleming 1962; Pierce 1984a, 1984b). Limited fossil evidence suggests that black stilts were once even more morphometrically distinct from pied stilts than today (Holdaway 1995).

The specific epithet *novaezelandiae* has often been misspelt, presumably because authors have followed the incorrect spelling of the 1953 and 1970 *Checklist of New Zealand Birds* (Ornithological Society of New Zealand Checklist Committee 1953; Kinsky 1970). The correct spelling is *novaezelandiae*, as spelt by Gould (1841), and as spelt in the current checklist (Turbott 1990). In his description of the black stilt, Gould (1841) separated the epithet into two capitalized words: *Novæ Zelandiæ*. The International Code of Zoological Nomenclature (1985; Article 5) requires that the original spelling is used, but that the epithet is one word, and is never capitalized. See Wood (1985) and Holdaway (1995) for further discussion of the nomenclature of stilts in New Zealand.

Literature

The biology of the black stilt is well described in the literature, mainly because of research undertaken in the late 1970s and early 1980s by Pierce (1982a, 1982b, 1983, 1984a, 1984b, 1985, 1986a, 1986b, 1987), which substantially expanded on earlier descriptive work (*e.g.* Hutton 1871; Buller 1875, 1888; Stead 1932; Oliver 1955; Soper 1967, 1976; Budgeon 1977; Merton 1977). Specific questions that relate to captive reared black stilts have been addressed recently by Reed (1986, 1994a, 1994b), Reed *et al.* (1993b) Adams (1995) and Hume (1995). Genetic variation of pied and black stilts was investigated by Green (1988). In addition to the published literature, much information about black stilts is recorded in unpublished files and reports of the Department of Conservation's Black Stilt Recovery Project in Twizel. It must be remembered that all recent studies of black stilts have been restricted to subsets of the remnant population, and therefore may not necessarily be representative of the original population. Nevertheless, these studies are highly relevant to current black stilt management. The following summary is drawn from many of the above sources, but relies mainly on Pierce's research.

Feeding ecology

Black stilts are wading birds and spend most of their time foraging in shallow water (< *c.* 18 cm) at the margins of streams and lentic wetlands. They prey primarily on a wide range of aquatic macroinvertebrates but also take small fish and terrestrial invertebrates (Pierce 1985, 1986b; pers. obs.). Most of the time, black stilts prey visually by walking through shallow water and pecking at invertebrates on the water surface, in the water column and on the substratum (Pierce 1985). Black stilts also employ non-visual feeding methods ('filtering', 'probing', 'scything' and 'lateral probing'; Pierce 1985), particularly when prey behaviour (Pierce 1986b) or weather conditions (*e.g.* rain, wind) make prey invisible (Pierce 1985). The rate of prey ingestion varies with weather, prey abundance and activity, prey species, and water velocity, and is negatively affected by the presence of potential competitors or predators (Pierce 1985, 1986b). Poor foraging conditions may cause black stilts to change feeding styles or to switch habitats (Pierce 1985). In winter, some shallow waters on lake deltas, and many small ponds and tarns in the Upper Waitaki River Basin may be covered with ice and therefore be unavailable as foraging habitat for black stilts.

Distribution and decline

Black stilts inhabited riverbeds, ponds, swamps, lake margins, estuaries and harbours throughout New Zealand in the late 19th century. However, they were most abundant on braided riverbeds in the eastern South Island and in central and eastern areas of the North Island (Buller 1888, Pierce 1984a). During the first half of the 20th century, the abundance of black stilts declined rapidly, and they became restricted in distribution mainly to the braided riverbeds and associated wetlands of lowland and inland Canterbury and Otago (Pierce 1984a).

By the 1940s, black stilt numbers were estimated at 500 -1000 (Pierce 1984a) and by the 1960s black stilts were breeding only in the Upper Waitaki River Basin. In the late 1970s the number of adult black stilts was estimated as 50 - 60, and in 1981 the New Zealand Wildlife Service began managing black stilts (Reed *et al.* 1993a). Black stilt management has been continued since 1987 by the New Zealand Department of Conservation (DOC). Under management, extinction has been averted, and the wild population has increased to at least 57 pure black stilts and 26 dark hybrids (Murray 1996).

The decline in their numbers and range corresponded to the loss and degradation of wetlands and the spread of introduced mammalian predators (especially cats, *Felis catus*, and ferrets, *Mustela furo*), but not to the spread of pied stilts (Pierce 1984a). Trapping trials and monitoring of black stilt and other river bird nests (DOC unpublished data), strongly suggest that predation on eggs and chicks was the proximal cause of the decline of black stilts. Hybridisation with pied stilts is considered a consequence rather than a cause of the decline of black stilts (Reed *et al.* 1993a). Black stilts strongly prefer to mate with conspecifics (Pierce 1984b), and won all territorial disputes with pied stilts observed by Pierce (1982b).

Life history and breeding biology

Black stilts sometimes form pair bonds before they are one year old, but they do not usually breed until they are 3 years old (Pierce 1982a; DOC, unpublished data). Pairs begin to copulate as early as the end of July, while they are still at lake deltas and other winter habitats (Pierce 1982a, DOC unpublished data, pers. obs.). In August, black stilts begin to move upriver from lake deltas, or to swamps, ponds, tarns or flooded pasture to nest. Nest site fidelity between breeding seasons is high (Pierce 1982a). Eggs are laid over four to five days, mainly between September and December (Pierce 1982a). However, black stilts will often renest in response to egg loss (*e.g.* because of predation, flooding, or removal by managers for captive rearing), and have been known to incubate until late January (D. Murray, pers. comm.). Four ovoid eggs are laid in nests that are always located where visibility is not restricted by vegetation, high banks or other obstructions. Nests are made from leaves, twigs and roots and are constructed on various substrata including bare shingle, mud, grass and hummocks of rushes (Pierce 1982a). Nests are usually constructed within 4 m of water (Pierce 1982a). Both parents incubate the eggs.

Black stilt chicks hatch after *c.* 25 days and are precocial. They are highly vulnerable to predation until they fledge 39 - 55 days after hatching (Reed *et al.* 1993). The long fledging period of black stilt chicks (*c.f.* 30 -37 days in pied stilts) and the poor distraction displays of adults probably contributed to the decline of the species (Pierce 1986a). In a comparison of pied and black stilts, Pierce (1986a) concluded that five other factors also make black stilts vulnerable to predation. These are: 1) nesting during periods of high predator activity; 2) nesting along stream banks, which are often frequented by predators; 3) solitary nesting; 4) high site fidelity, and 5) lack of a disruptive camouflage pattern.

Around March, black stilts move from their summer habitats back to their winter habitats. Most black stilts overwinter on the deltas formed where large braided rivers flow into the Upper Waitaki lakes. There are six large deltas on four lakes. These are: the Tasman Delta of Lake Pukaki, the Godley and Cass Deltas of Lake Tekapo, the Hopkins Delta of Lake Ohau, and the Ahuriri and Tekapo/Ohau Deltas of Lake Benmore (Fig. 1.2). I define 'delta' and present detailed descriptions and photographs of the abovenamed deltas in Chapter 2. Juvenile black stilts remain with their parents through winter until about August when they are chased away by their parents.

Management

The Department of Conservation is responsible for the protection and management of black stilts. Their current recovery strategy for the species is detailed in the Black Stilt Recovery Plan (Reed *et al.* 1993a). The long term goal is to establish self-sustaining populations of black stilts in the wild. Currently, black stilt management includes egg manipulation and cross-fostering, predator control, captive breeding, habitat protection and enhancement, and research on agents of decline other than predators (Reed *et al.* 1993a). Management priority is given to pure black (Node J) and dark hybrid stilts (Nodes G,H and I).

In addition to the management described in the Black Stilt Recovery Plan (Reed *et al.* 1993a), black stilts are also expected to benefit from a habitat enhancement project called Project River Recovery (PRR). PRR is administered by DOC and funded by the Electricity Corporation of New Zealand (ECNZ). PRR was established by an agreement between ECNZ and DOC which recognises the impact of hydroelectric power generation on wetlands in the Upper Waitaki River Basin (Anon. 1990). PRR's overall objective is to mitigate habitat loss and degradation caused by hydroelectric power generation, and one of its aims is to enhance wetlands for black stilts. Research presented in this thesis is concerned with habitat protection and enhancement for black stilts, and complements both PRR and the Black Stilt Recovery Project.

Hydroelectric development dramatically changed lakes, rivers and other wetlands in the Upper Waitaki River Basin. (See Martin (1991), Chapter 9, for a general account of the development of the Waitaki River for HEP.) These changes were detrimental to black stilts in many ways. Most significantly, flows in the Pukaki, Ohau and Tekapo Rivers were reduced to almost nil and the open shingle riverbeds were soon invaded by crack willows (*Salix fragilis*), Russel lupins (*Lupinus polyphyllus* cultivar), gorse (*Ulex europeaus*) and briar (*Rosa rubignosa*). Invasive plants increase

the height of, and stabilize, riverbed islands by trapping silt and debris and protecting them from floods. The dense plant growth on these islands forces birds to nest near the water's edge, where they are vulnerable to floods. At the same time, stable, high islands constrain the rivers to deep channels which do not provide the extensive shallow feeding habitats found in unmodified braided rivers. Densely vegetated islands provide cover for introduced mammalian predators (Pascoe 1995), and low flows enable predators to move easily between islands (Pierce 1987; Rebergen 1994).

The abstraction of water from rivers also caused a reduction in the number and extent of other wetlands, presumably because water tables were lowered. Large areas of black stilt habitat were also lost when riverbeds and adjacent wetlands were flooded by the raising of Lakes Benmore, Tekapo and Pukaki. Fluctuations in the levels of these lakes as a result of HEP generation also have the potential to affect black stilts.

HEP GENERATION AND THE ELECTRICITY CRISIS

Energy users in New Zealand, except for the transport sector, are heavily dependent on electricity. In 1992, electricity accounted for 66 % of domestic energy use, 33 % of industrial, and 44 % of commercial and agricultural energy use (Evans 1994). Typically, about 71 % of New Zealand's annual electricity demand is met by hydroelectric power generation and the balance is met by geothermal and fossil fuel power stations (ECNZ Annual Report 1994). ECNZ supplies *c.* 95 % of New Zealand's electricity (Davison *et al.* 1992). A problem with hydroelectric power generation, particularly in New Zealand, is that electricity demand does not correspond to the natural availability of water. Runoff is lowest in winter and highest in spring and summer, whereas electricity demand is greatest in winter and lowest in summer (Fitzharris 1992). Therefore, to ensure that water is available to generate electricity as required, runoff from the mountains is stored in artificial and raised 'hydro' lakes throughout New Zealand.

The electricity-generating potential of water stored in a hydro lake depends upon the generation capacity of downstream power stations and the volume of water in the lake that is available to ECNZ. The volume of water available depends on the range of levels within which ECNZ may legally operate the lake, and the lake's area and bathymetric profile. Sixty-seven percent of New Zealand's hydro storage capacity is provided by Lakes Pukaki (44.4%) and Tekapo (21.5 %), both of which are in the Upper Waitaki River Basin in the central South Island (Davison *et al.* 1992).

A second problem that ECNZ faces when generating HEP in New Zealand is that steep terrain, short rivers and narrow valleys limit lake size and therefore hydro storage. Hydro storage in New Zealand is only 12 % of annual electricity use (6 weeks), compared to 18 - 20 % in Iceland, 133 % in Tasmania and 785 % in Brazil (Davison *et al.* 1992). A further problem is that seasonal inflows to hydro lakes are difficult to predict because of variation in snow storage and spring precipitation (Fitzharris 1992).

The 1992 electricity shortage

In late 1991 and early 1992 lower than average precipitation and snowmelt contributed to lower than average storage in the South Island hydro lakes through summer 1991/1992 and autumn 1992 (Davison *et al.* 1992; Fitzharris 1992). Storage in hydro lakes was lowered further by high electricity usage because of cold weather, and the provision of an increased supply of hydro-generated electricity to the North Island, via the recently increased capacity of the Cook Strait cable. By April 1992, ECNZ was apparently concerned about low lake levels (Davison *et al.* 1992). In May, ECNZ began to increase its use of non-hydro generating capacity, requested Comalco (who use 15 % of New Zealand's electricity to smelt aluminium) to reduce demand, and investigated cloud seeding to increase rainfall. The extent to which ECNZ could have predicted the water shortage and ensuing electricity crisis in 1992 was investigated by The Electricity Shortage Review Committee (Davison *et al.* 1992).

In addition to the above measures, ECNZ applied on 15 May 1992 to the Canterbury Regional Council for access to an additional 5 m deep layer of water from Lake Pukaki. That is, to use the water between 513 and 518 metres above sea level (m a.s.l.), in addition to their usual winter operating range of 518 to 532.5 m a.s.l. Access to an additional 5 m of water in Lake Pukaki would provide up to 300 GWh of extra electricity (3 - 4 days supply for New Zealand).

The prospect of such an extreme drawdown of Lake Pukaki, and the already low levels of the Upper Waitaki lakes raised considerable concern about black stilts among the public and conservation organisations (*e.g.* Anon. 1992; and letters to the editor in daily newspapers, May - July 1992). The principal concern was that black stilts, which overwinter on the deltas of the Upper Waitaki lakes, would struggle to find sufficient food at low lake levels (Anon. 1992; Hughey 1992; James 1992; Murray 1992, 1993). However, ecological knowledge of black stilts on lake deltas was limited, and the effects - if any - of lake levels on black stilts were unknown.

Faced with public opposition to further lowering of Lake Pukaki (for many reasons), ECNZ went to the Government, which passed the Lake Pukaki Water Level Empowering Act on 2 July 1992. The Act provided ECNZ with emergency access to the additional 5 m of water (513 - 518 m a.s.l.) from Lake Pukaki. However the water was not required and the Act was later repealed.

Although the Act has been repealed and the 1992 electricity shortage has been and gone, the potential effects of low lake levels on black stilts remain an issue for black stilt conservation and HEP generation. Low and fluctuating lake levels remain an issue because ECNZ is likely to reapply for emergency access to the additional 5 m of water in Lake Pukaki. (ECNZ was already in the process of applying for access to this water before the 1992 electricity shortage; Davison *et al.* 1992). At a broader level, decisions about future sources of energy in New Zealand have potential environmental and economic consequences beyond black stilts and the Upper Waitaki lakes. For example, other potential sources of electricity such as gas- or coal-burning thermal stations, wind power, and the proposed Ngakawau hydro station in North Westland would be expensive (R. Sutton, Southpower, pers. comm.) and pose their own environmental threats.

An understanding of the effects of low and fluctuating lake levels on black stilts, and other species that inhabit lake deltas, was desired by both DOC and ECNZ. In mid 1992, ECNZ agreed to fund a 3 year study that would address this issue. Part of this study was concerned with black stilts in particular, and forms Part One (Chapters 2 to 5) of my thesis.

My approach

In Chapters 2 to 5 of this thesis I investigate the effects of low and fluctuating lake levels on black stilts. Although the principal concern during the electricity shortage of 1992 was the level of Lake Pukaki, I extended my investigation to Lakes Tekapo, Ohau and Benmore. I took a wider approach because ECNZ's integrated operation of the Upper Waitaki lakes potentially affects all black stilts that overwinter on lake deltas.

To understand how lake levels might affect black stilts, it is essential to have a clear picture of the type of habitat provided by the six large lake deltas of the Upper Waitaki lakes. In Chapter 2, I present detailed descriptions of these deltas based on my research and a review of the literature. I conclude that the main physical effect (*i.e.* not directly related to food supply or predation) of low or declining lake levels is an increase in the amount of open space available to black stilts.

Concerns about the effect of lake levels on black stilts imply that lake levels may affect the viability of the black stilt population, which depends most directly on breeding success (O'Driscoll and Veltman unpub. ms; Reed *et al.* 1993a). Black stilt breeding success, defined here as number of chicks fledged, is low and variable. For example, the total numbers of chicks that fledged in the wild during the past five breeding seasons were: 4 (1990/1991 breeding season), 5 (91/92), 9 (92/93), 2 (93/94), and 7 (94/95) (D.P. Murray, DOC, pers. comm.). Breeding success is also strongly affected by predators and management by DOC. Therefore, only large changes in numbers of chicks fledged, associated with changes in lake levels, would provide convincing evidence for effects of lake levels on black stilts breeding success. (A long term study would be able to detect smaller differences, at least in theory, but was beyond the scope of this thesis.) Furthermore, large changes in breeding success could only be positive, because the number of chicks fledged annually is currently close to nil. No large positive change in breeding success followed the 1992 electricity shortage.

To detect potential effects of lake levels on black stilts it was therefore necessary to investigate aspects of black stilt biology that would be likely to affect breeding success. Breeding success could be influenced by low or fluctuating lake levels via two main pathways (Fig. 1.3). First, changing lake levels might affect the availability of aquatic invertebrates on which black stilt feed, and therefore breeding success. Changes in lake levels have long been known to affect aquatic invertebrates at lake margins overseas (*e.g.* Moon 1935; Hynes 1961; McLachlan 1970; Hunt and Jones 1972) and in New Zealand (Winter 1964; Greig 1973; Stark 1990). My preliminary observations of black stilt habitat on deltas of the Upper Waitaki lakes suggested that food supplies for black stilts were likely to vary within and among lakes. If winter food supply affects black stilt condition, as seems likely, it may indirectly affect breeding success. Food supply should not only be measurable directly, but should also be reflected in foraging behaviour (*e.g.* Lovette and Holmes 1995). In Chapter 3, I report the results of investigations into black stilt food supplies and foraging behaviour on lake deltas at a range of lake levels.

The second way in which lake levels could influence black stilt breeding success is by influencing numbers of birds present on lake deltas, and therefore the chances of unpaired birds finding mates. Finding mates is likely to be problematic for black stilts because of their low population density (Reed 1994a). However, the congregation of black stilts on lake deltas during winter provides an opportunity for new pairs to form (Murray 1993). In addition, the number of black stilts present on a lake delta provides an indication of the suitability of that delta as black stilt habitat. In Chapter 4, I present an analysis of black stilt counts over the past 15 years. The counts show that

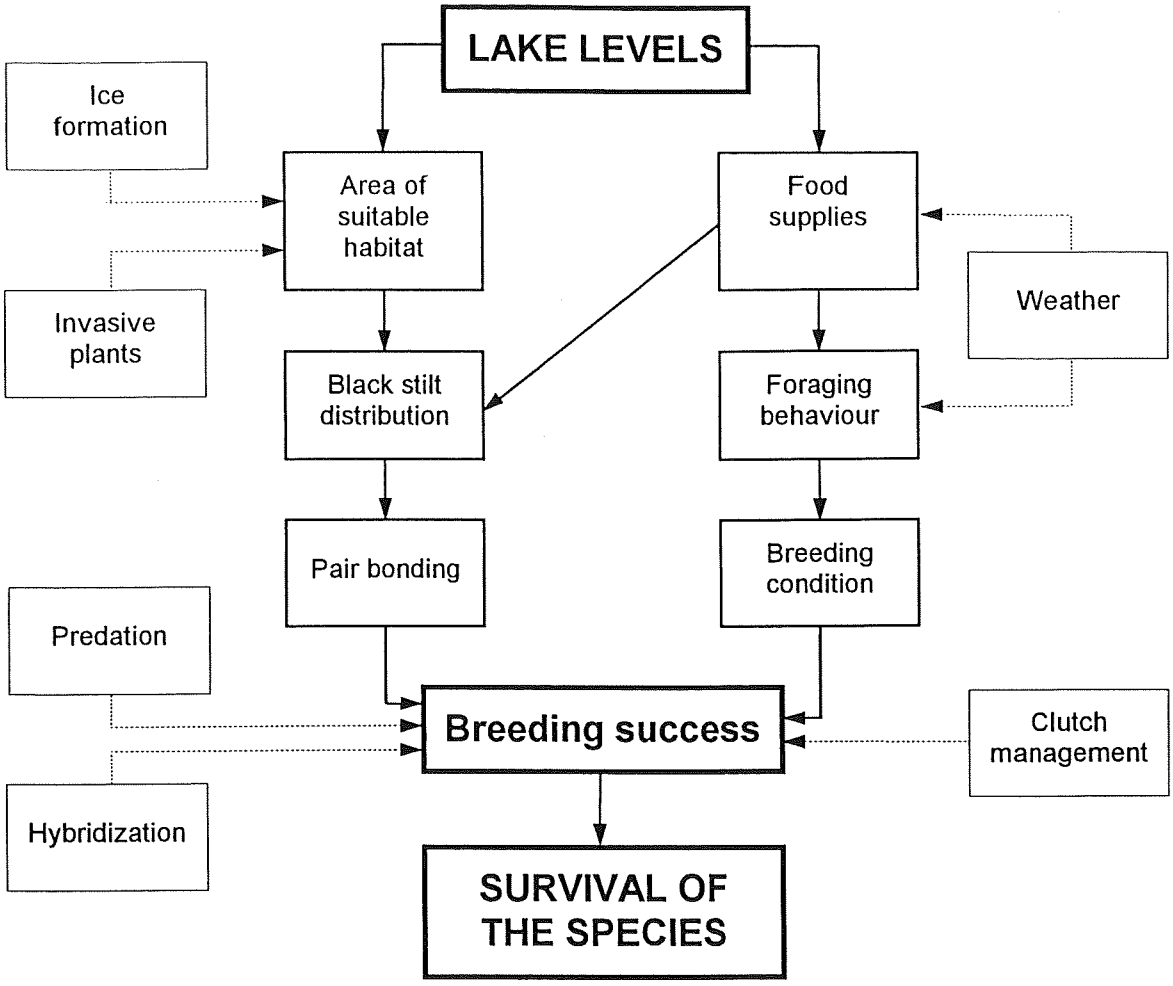


Figure 1.3. The principal ways in which lake levels potentially influence black stilt breeding success and therefore the survival of the species. Dashed arrows indicate factors that are not related to lake levels, but which may modify the effects of lake levels or affect breeding success of black stilts directly.

the numbers of black stilts on three of the six deltas of the Upper Waitaki lakes were related to lake levels.

The Ahuriri and Tekapo/Ohau Deltas on Lake Benmore currently provide important black stilt habitats, and are used by 50 % - 66 % of the present-day black stilt population (Appendix 2). They are likely to be used by more black stilts in the future because they provide habitat for captive-reared black stilts that have been released to the wild, and because they are near several wetlands that are likely to be developed for black stilts. Lake Benmore is normally held at a constant level (mode: 361.20 m a.s.l.) because its function is to provide a head of water for Benmore Power Station, not to provide storage. However, during the electricity shortage in 1992, Lake Benmore was lowered to 357.70 m a.s.l., 3.50 m below its normal level. The habitat exposed on the Ahuriri

and Tekapo/Ohau Deltas of Lake Benmore appeared to provide excellent habitat for many birds, and up to 20 black stilts were seen on the Ahuriri Delta on 18 July 1992 (Murray 1993). A drawdown of Lake Benmore for willow clearance during February to March 1994 provided me with an opportunity to investigate black stilt numbers, foraging behaviour and food supply on the Tekapo/Ohau and Ahuriri Deltas at low lake levels. I describe this investigation in Chapter 5.

WETLAND ENHANCEMENT

One of the aims of black stilt management is to establish black stilt habitat - particularly breeding habitat - in which risk of predation is low (Anon. 1990a; Reed *et al.* 1993a). The risk of mammalian predation can almost be eliminated by enclosing wetlands within electric fences, and by trapping, poisoning and shooting predators within enclosures. Predators can also be deterred from using wetlands by controlling vegetation and prey populations (*e.g.* rabbits), and using water as a barrier. However, predator-protected wetlands will only benefit black stilts if they use these sites, rather than the many other wetlands in the Upper Waitaki River Basin. In particular, predator-protected wetlands can only be expected to reduce predation on eggs and chicks if black stilts nest within them (*e.g.* Pierce 1982b).

How can managers increase the chances that black stilts will forage and nest at predator-protected wetlands? One way is simply to protect established nesting sites. This approach was tried with some success in the early 1980s, at two sites near Lake Tekapo, Mick's Lagoon and Mailbox Inlet. Thus, in the first breeding season after predators were excluded from Mailbox Inlet, eight black stilts fledged, whereas only two had fledged the previous season (Pierce 1982b).

However, protecting established nest sites has two main disadvantages. First, there is no guarantee that black stilts will continue to nest at predator-protected sites. Thus, a total of 17 black stilts nested at Mick's Lagoon and Mailbox Inlet in the first five breeding seasons after predator protection work was undertaken (1981/1982 to 1985/1986). In the subsequent ten breeding seasons (1986/1987 to 1995/1996) only four black stilts have nested at these sites (D.P. Murray, DOC, pers. comm.). Second, many nest sites cannot be protected because they are unavailable (*e.g.* those on private land) or are not suited to fencing (*e.g.* because they are in riverbeds that are flood-prone).

Two other strategies that may encourage black stilts to use predator-protected wetlands are: 1) release captive reared black stilts within enclosures, and 2) ensure that wetlands are as attractive as possible to black stilts. Wetlands can be made physically attractive to black stilts by providing large areas of shallow water with gently sloping, convoluted edges. The wetlands should also be free of tall vegetation or high banks. In addition to physical form, the type and amount of food supplies available in wetlands will almost certainly influence black stilt habitat selection.

Although the influence of food supply on habitat selection by black stilts has not been tested formally, Pierce observed that they chose to forage (Pierce 1985, 1986b) and nest (Pierce 1982b,1986a) at sites with abundant food supplies. Furthermore, the influence of food supply on habitat selection, including nest site selection, has frequently been demonstrated in many birds (see Cody 1985, and references therein). In Part Two of this thesis (Chapters 6 to 11), I investigate techniques for enhancing food supplies in wetlands.

My research on wetland enhancement complements my research on the effects of lake levels on black stilts. By providing safe alternative habitat to lake deltas throughout the year, enhanced wetlands may buffer detrimental effects of fluctuating lake levels. Provision of enhanced wetlands may also reduce the vulnerability of black stilts to human disturbance on riverbeds (*e.g.* through the presence of four wheel drive vehicles, and domestic and farm dogs), and to natural and HEP-induced floods.

Other potential advantages of enhanced wetlands include: 1) good food supplies enable chicks to grow quickly (Reed 1986, 1994b). Chicks that grow quickly fledge early (Pierce 1986a), and thus shorten the period during which they are most vulnerable to mammalian and avian predators; 2) unpaired black stilts should be more likely to find mates if they congregate at enhanced wetlands; 3) enhancement of wetlands is less expensive than many other management options (*e.g.* vegetation removal from riverbeds), and 4) enhancement of wetlands should benefit other native flora and fauna.

My approach

Although food supply is likely to influence black stilt nest site selection, little is known about the type and amount of food that occurs at natural nest sites. A knowledge of food availability at nest sites is a prerequisite for evaluation of attempts to enhance food supplies at wetlands. In

Chapter 6, I report the results of a survey of the community composition and biomass of aquatic invertebrates at black stilt nest sites.

The abundance, biomass and species composition of aquatic invertebrates are known to be influenced by the physical structure and organic content of the substratum (reviewed by Minshall 1984). Consequently, wetland managers throughout the world have manipulated food supplies for birds in wetlands by manipulating the substratum (*e.g.* Street 1983; Helmers 1986; Murkin and Kadlec 1986). Observations of substrata in local wetlands suggested that this technique would be worth attempting in the Upper Waitaki River Basin. In Chapters 7, 8, and 9, I report the results of three substrate manipulation experiments. The first experiment involved the addition of various substrata to 1 m^2 quadrats. The results were very encouraging and were reported by Sanders and Maloney (1994). This paper is reproduced with minor stylistic alterations in Chapter 7. (The abstract, acknowledgements and references are incorporated elsewhere in this thesis).

Following the small-scale substrate addition experiment, I conducted a more realistically scaled substratum manipulation experiment. Substrata were added to, or manipulated in, 10 m diameter ponds at six sites throughout the Upper Waitaki River Basin. The results of this experiment are presented in Chapter 8 in the format of a scientific paper. Because it is written in paper format, the introduction to Chapter 8 partly overlaps this introduction to the thesis as a whole.

In early September 1994, PRR undertook habitat enhancement at Mick's Lagoon, one of the sites at which I had conducted the pond experiment. Results from my substratum experiment indicated that disturbing the substratum at Mick's Lagoon and adding patches of barley straw would enhance invertebrate standing crop. I tested this prediction by measuring invertebrate biomass, abundance and community composition at Mick's Lagoon, in disturbed and undisturbed areas, with and without additions of straw. This experiment is reported in Chapter 9.

Observations of captive black stilt chicks suggested that they preferred or were able to capture and consume some prey species better than others. The black stilt breeding facility at Twizel provided an opportunity to test whether black stilt chicks would capture and consume the most abundant prey species produced in the substratum manipulation experiments (Chapters 7 - 9). In Chapter 10, I report the results of feeding trials on captive black stilt chicks

Although the pond experiment was designed as an invertebrate experiment, birds, including black and pied stilts, foraged and nested at some of the ponds. A detailed study of bird habitat use was

beyond the scope of this study, but I was able to make limited behavioural observations on pied stilts. In addition, records of the use of ponds by black stilts were kept by DOC and Lynn Adams, who was studying black stilts that had been released from captivity as part of her M.Sc. thesis (Adams 1995). My behavioural observations and these records of habitat use by black stilts show that wetlands can be enhanced for black stilts. I present this information in Chapter 11.

In Chapter 12, I review my research on habitat enhancement and lake levels, and make recommendations for management of wetlands and lakes for black stilts in the Upper Waitaki River Basin.

PART ONE

Lake levels

CHAPTER 2

Descriptions of lake deltas

INTRODUCTION

Black stilts almost always inhabit sites that are near water where they have an unobstructed view of the surroundings. In particular, they spend much of their time at or near the water's edge, on gently sloping, sparsely vegetated shores of rivers, tarns and lake deltas (Pierce 1982a, 1983; Robertson *et al.* 1983; this thesis, Chapter 4). Lake deltas are those areas delimited by the sides of the valley at the head of a lake, and for the purposes of this thesis, a line parallel to and 100 m upstream from the maximum control level of the lake, and the lake edge. In the Upper Waitaki Basin, six deltas are found where large braided rivers enter the four main lakes (Figs. 1.2, 2.1). On lake deltas, the shore profile, substratum composition, and proximity of vegetation to the lake edge vary with lake levels. Thus, one way in which lake levels could influence the use of deltas by black stilts is by affecting their physical characteristics. In this chapter, I describe how the shore profile, substratum composition, and proximity of vegetation to the lake edge vary with lake level, on the six main deltas of the Upper Waitaki Lakes. The six deltas are:

1. the Tasman Delta of Lake Pukaki,
2. the Godley Delta of Lake Tekapo,
3. the Cass Delta of Lake Tekapo,
4. the Hopkins Delta of Lake Ohau,
5. the Ahuriri Delta of Lake Benmore, and
6. the Tekapo/Ohau Delta of Lake Benmore.

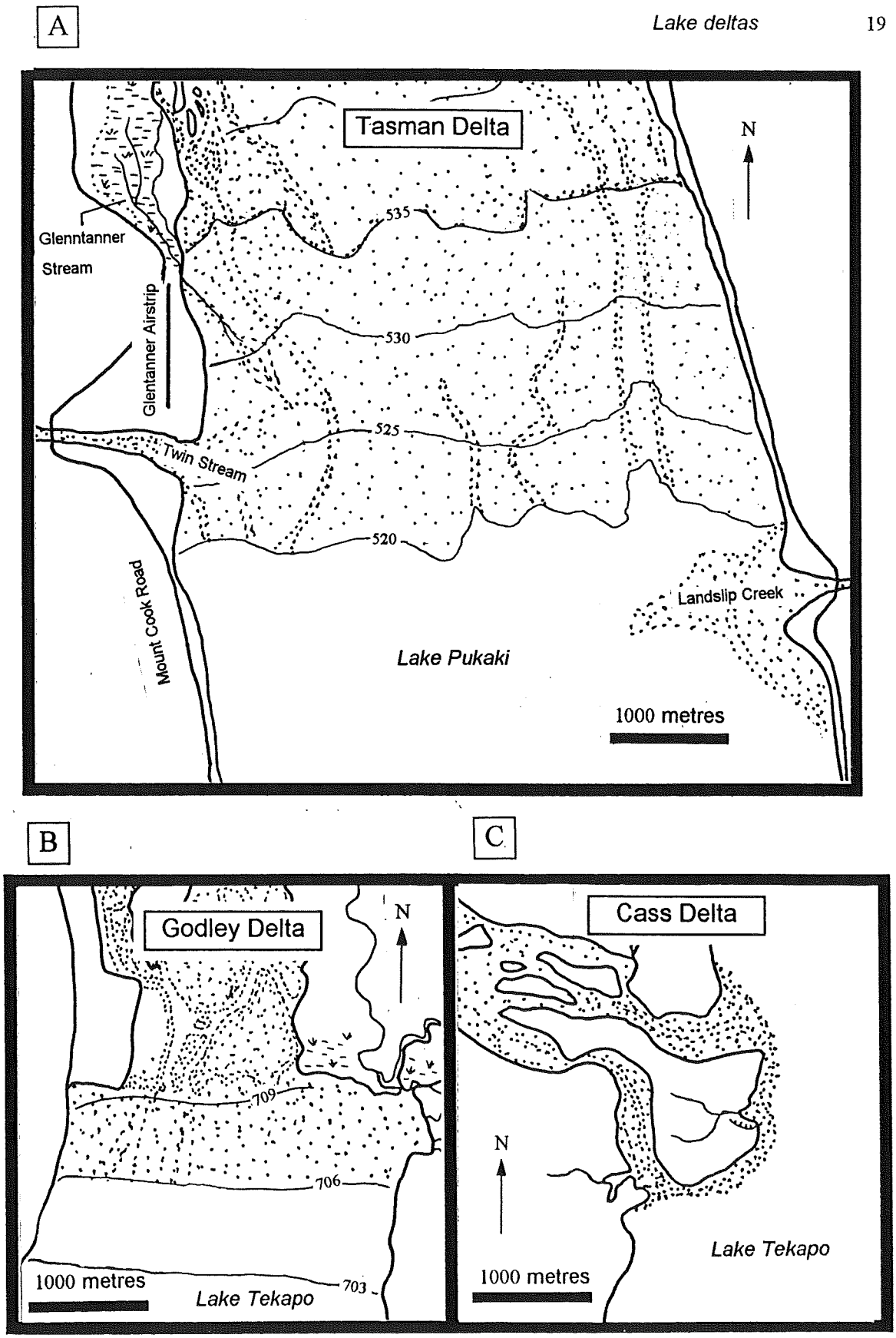


Figure 2.1. Maps of lake deltas in the Upper Waitaki Basin on which black stilts overwinter (see Fig. 1.2 for locations of deltas within the Upper Waitaki Basin). Approximate contours of the deltas/lake beds, in metres above sea level, are indicated (see following page for legend). Contours are based on my surveys of lake deltas, topographical maps (NZMS 1 & 260), and aerial photographs. Numerous braids of the Tasman River and side streams flow over the Tasman Delta, but are not shown here (instead, see Fig.2.6).

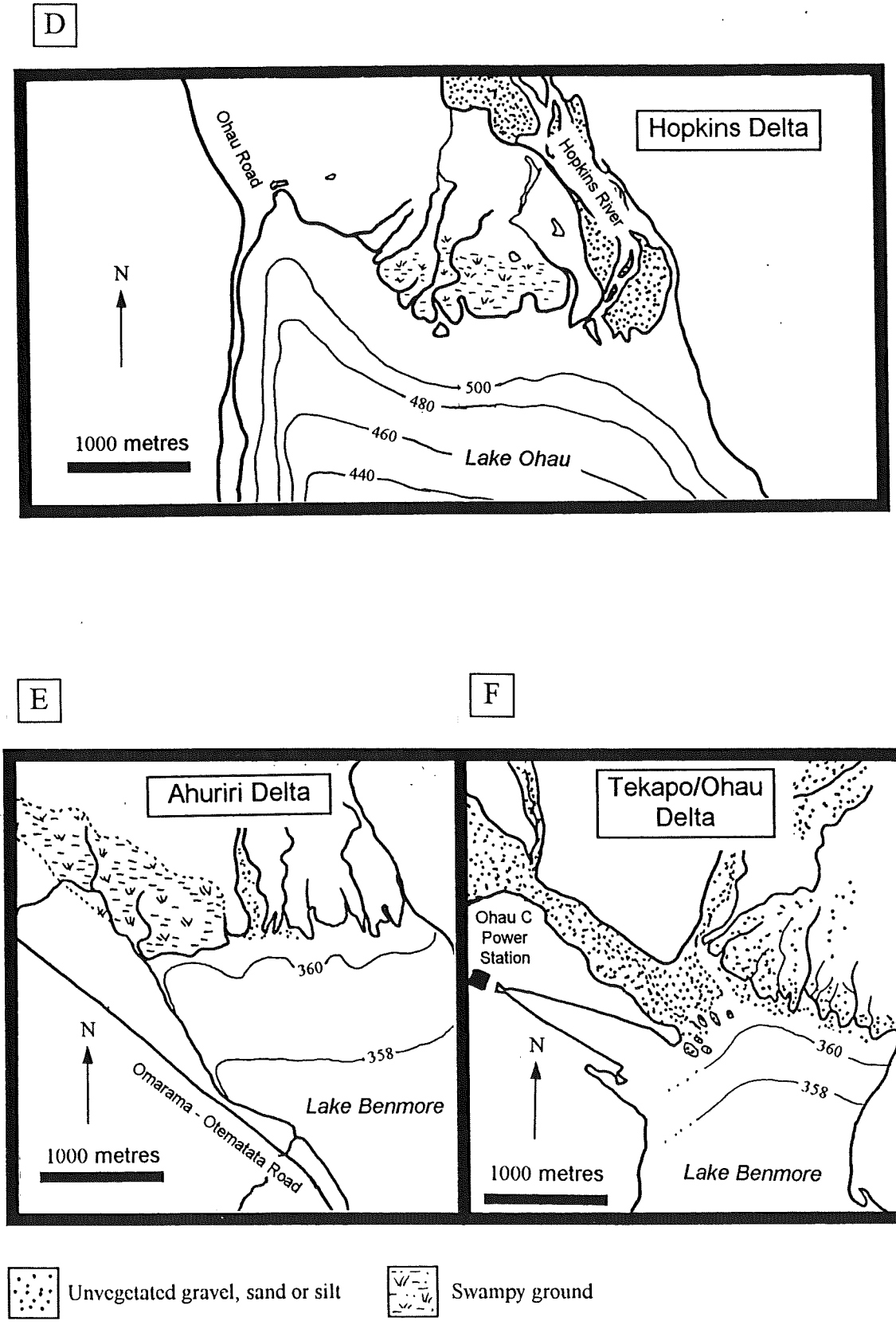


Figure 2.1 continued.

THE UPPER WAITAKI LAKES

Lakes Pukaki, Tekapo and Ohau are glacial lakes that were dammed and raised for hydroelectric power generation, mainly in the 1960s and 1970s (Martin 1991; Soons 1992). In contrast, Lake Benmore is an artificial lake formed by damming the Waitaki River in the early 1960s. Levels of these lakes are controlled to a large extent by the Electricity Corporation of New Zealand (ECNZ), which is required to operate them between specific maximum and minimum control levels (Anon. 1981a, 1981b, 1988, 1990). If necessary however (*e.g.* during floods or droughts), ECNZ may operate lakes up to 'design flood levels', or down to 'extreme minimum control levels'.

Sixty seven percent of New Zealand's hydro storage capacity is provided by Lakes Pukaki and Tekapo, and both are operated over wide ranges. For example, between 1 January 1980 and 2 September 1994, their levels fluctuated over ranges of 14.34 m and 10.46 m, respectively (Table 2.1; see also Mark 1987). Typically, Lakes Pukaki and Tekapo are filled by rain and snowmelt in spring and summer, and are drawn down gradually through autumn and winter, to meet high electricity demands (Figs. 2.2, 2.3). In contrast, Lakes Ohau and Benmore are normally operated at relatively constant levels (Table 2.1; Figs. 2.4, 2.5) because their principal function is to provide heads of water for Ohau A and Benmore power stations, not to provide storage.

In 1992, Lakes Pukaki and Tekapo were unusually low at the beginning of the year, and fell to their typical winter minima 2 - 3 months earlier than usual (Figs. 2.2, 2.3). Lake Benmore was lowered more than 3 m below its modal level (360.20 m a.s.l.) during the 1992 electricity crisis (Fig. 2.5), but the level of Lake Ohau was not affected (Fig. 2.4).

Table 2.1. Data describing the four large Upper Waitaki Lakes. Operating levels are quoted from ECNZ operating instructions (Anon. 1981a, 1981b, 1988, 1990). Recent maximal and minimal lake levels were extracted from data provided by Workscorp and the National Institute of Water and Atmosphere. All levels are expressed as metres above sea level (m a.s.l.). Note that maximum control level varies throughout the year. Background information is taken from Livingston *et al.* (1986) and Stout (1975).

Lake:		Pukaki	Tekapo	Ohau	Benmore
OPERATING LEVELS					
Design flood level		534.10	713.05	524.15	362.60
	March	532.00	710.00	520.25	361.45
	April	532.00	710.30	520.25	361.45
Maximum	May	532.50	710.60	520.25	361.45
control	June	532.50	710.90	520.25	361.45
level	July	532.50	710.90	520.25	361.45
	August	532.50	710.30	520.25	361.45
	Sept. - Feb.	532.00	709.70	520.25	361.45
Minimum control level		518.20	702.10	519.75	360.50
Extreme minimum control level		518.00	701.80	519.45	355.25
RECENT MAXIMAL AND MINIMAL LEVELS					
Maximum level during this study*		531.84	710.16	520.41	361.39
Minimum level during this study*		519.10	703.13	519.69	357.61
Maximum level 1/1/80 - 2/9/94		533.26	712.55	522.23	361.73
Minimum level 1/1/80 - 2/9/94		518.92	702.09	519.17	356.83
BACKGROUND INFORMATION					
Area (km^2)		129	87	54	67
Trophic status		Ultra-oligotrophic	Ultra-oligotrophic	Oligotrophic	Oligotrophic
Visibility: Secchi disk (m)		0.2 - 1.0	1.2 - 7.0	4.6 - 21.74	0.9 - 5.2
Main inflowing rivers		Tasman	Godley Cass	Hopkins	Ahuriri Tekapo Ohau Pukaki

* Study duration: 1 July 1992 - 31 August 1992, and 1 March - 31 August, 1993 and 1994.

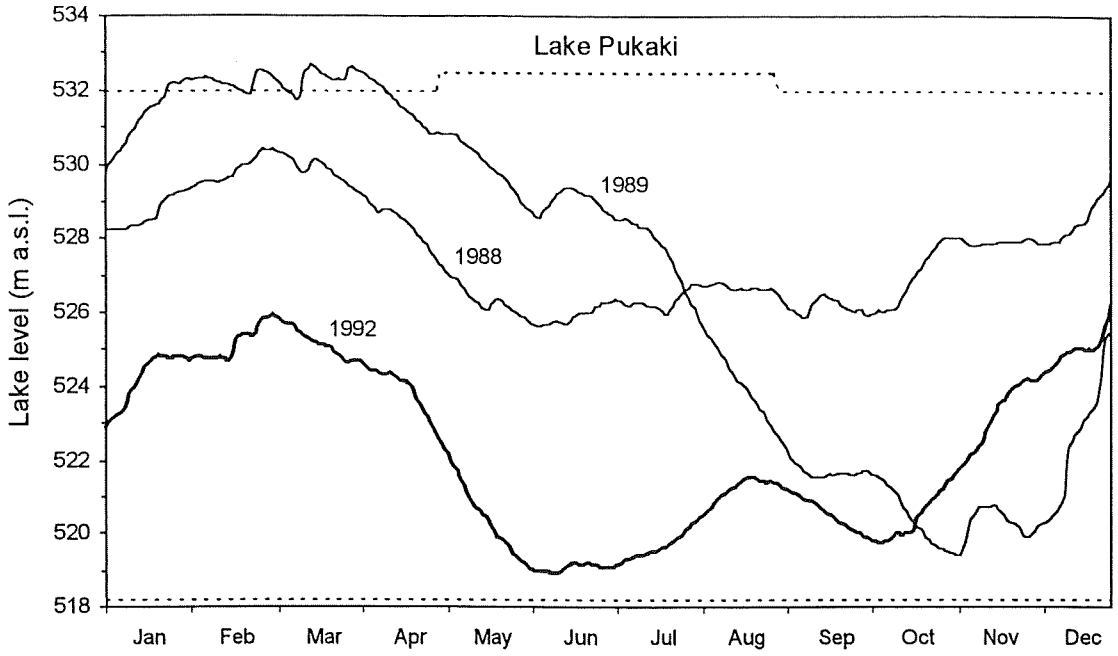


Figure 2.2. Changes in the level of Lake Pukaki during three representative years. Lake levels in 1989 were typical of most years, but those in 1992 and 1988 were unusually low and high, respectively. The dotted lines show the maximum and minimum control levels (see also Table 2.1). Lake level data presented in Figures. 2.2 - 2.5 were provided by Workscorp and the National Institute of Water and Atmosphere. Note that scales of Y-axes differ in Figures 2.2 - 2.5.

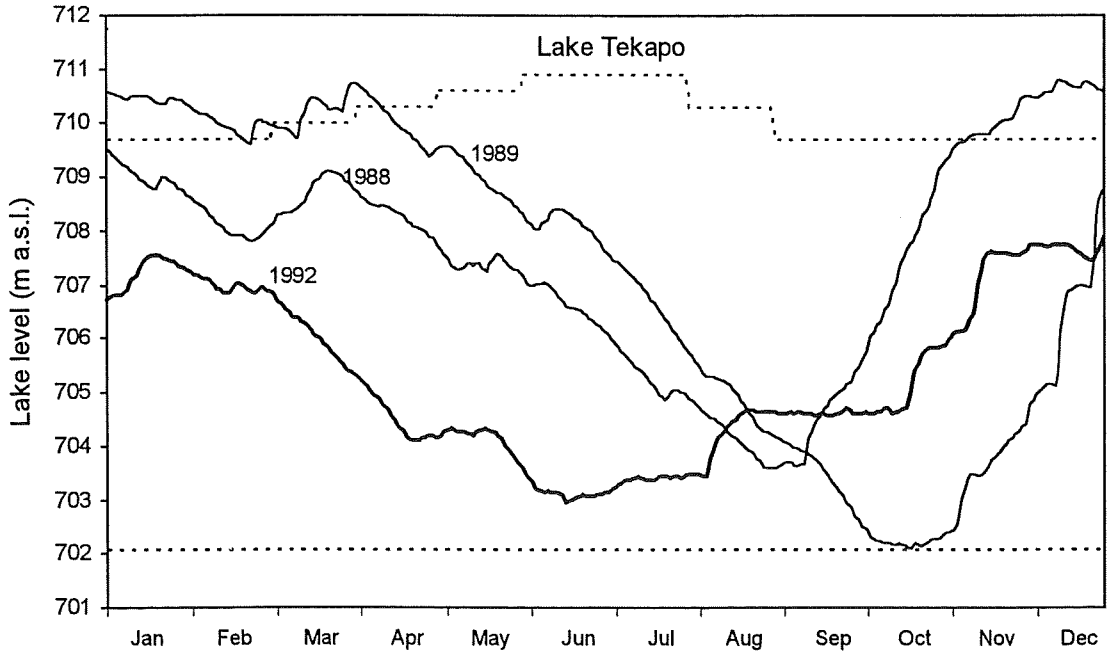


Figure 2.3. Changes in levels of Lake Tekapo during three representative years. Lake levels in 1989 were typical of most years, but those in 1992 and 1988 were unusually low and high, respectively. Dotted lines as in Figure 2.2.

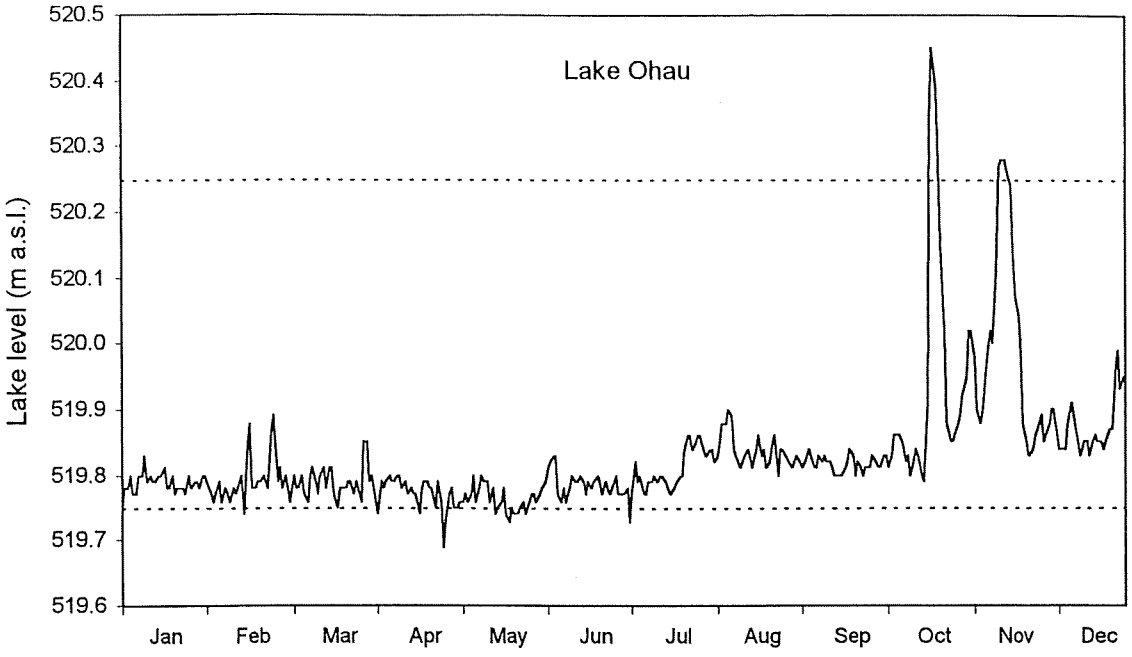


Figure 2.4. Fluctuations of Lake Ohau during 1992. Other years (1980 - 1994) exhibited little variation about the mean level of 519.8 m a.s.l. The peaks in October and November probably reflect episodes of high spring rainfall and are not typical of most years. Dotted lines as in Figure 2.2.

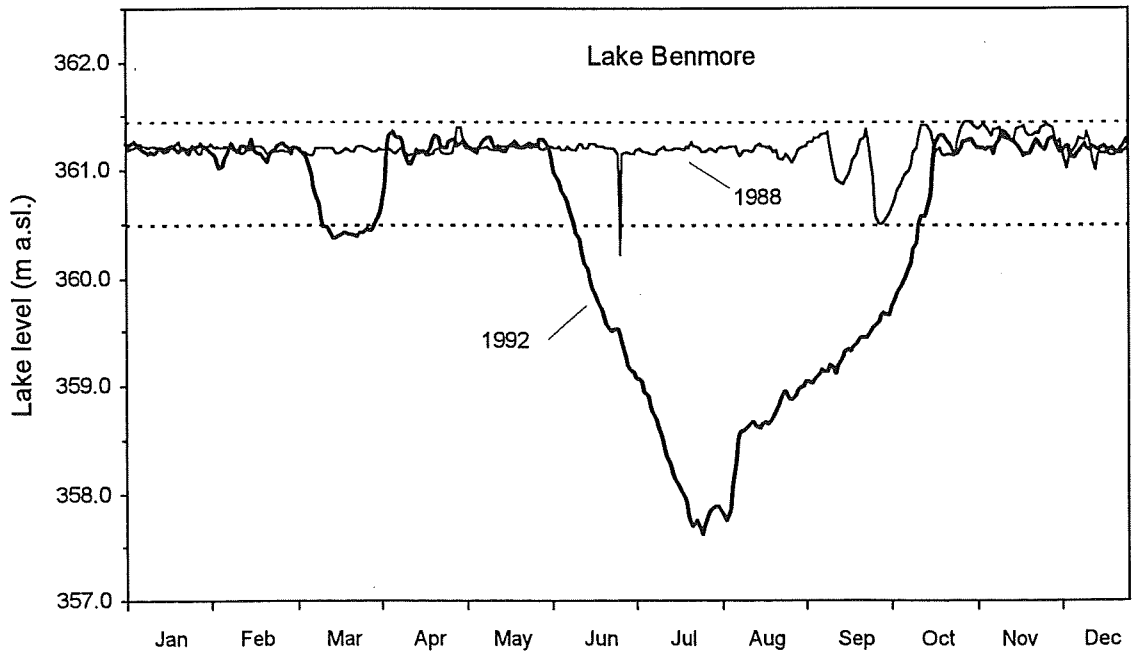


Figure 2.5. Fluctuations of Lake Benmore during a typical year (1988) and the year of the electricity crisis (1992). Dotted lines as in Figure 2.2.

THE LAKE DELTAS

Tasman Delta, Lake Pukaki

The Tasman Delta (Fig. 2.1A, 2.6 - 2.9) is five kilometres wide, and provides extensive open habitat for black stilts at all lake levels. The lower reaches of the Tasman River also provide physically suitable habitat for black stilts because, unlike other rivers in the Upper Waitaki Basin, they have not been invaded by exotic plants such as lupins (*Lupinus polyphyllus* cultivar), crack willows (*Salix fragilis*), and rosehips (*Rosa rubignosa*).

When the water level of Lake Pukaki is above *c.* 524 m a.s.l., the substratum at the lake edge (Fig. 2.7) is dominated by cobbles (> 64 mm), pebbles (16 - 64 mm), and gravels (2 - 16 mm) (as defined by Cummins, 1962). However, as the level of the lake falls, it exposes progressively finer particles. Below *c.* 523 m a.s.l., the substratum consists mainly of sand and silt (Figs. 2.6, 2.8). The fine substratum of the lower delta is susceptible to erosion by side streams and braids of the Tasman River, which can cut down into the delta to form deep, steep-sided gullies (Fig. 2.9). Furthermore, at low lake levels, wave action can result in the formation of steep banks of sand and silt on the lake shore (Fig. 2.9). These steep banks appear to discourage, and may prevent, black stilts from foraging, particulary if deep water occurs immediately adjacent to them (pers. obs.; Department of Conservation staff, pers. comm.). However, although the habitat at the lake edge changes dramatically as lake level drops, other habitat provided by streams flowing across the upper delta (above 524 m a.s.l.) remains largely unchanged. For example, a shallow, slow flowing stream adjacent to the Glentanner airstrip (Glentanner Stream) is available at all but the highest lake levels (< 531.5 m a.s.l.), and is used frequently by black stilts (pers. obs.; Department of Conservation unpub. data).

Thus, low levels of Lake Pukaki change the physical habitat of black stilts in two main ways. On the one hand, the lake edge and lower reaches of the delta can become physically unsuitable for black stilts if steep banks form. At the same time, low lake levels expose a large area of habitat that would otherwise be unavailable to black stilts (regardless of its 'quality'). The habitat on the upper delta (> 523 m a.s.l.) is not affected by low lake levels, except that the distance to the lake edge becomes greater. Because the Tasman Delta has a very low longitudinal (north-south) gradient (*c.* 1:150), the lake edge typically moves 1200 - 1800 m horizontally during winter drawdown. Water of stilt foraging depth (< 18 cm) extends more than 25 m offshore along much of the lake edge, at all lake levels, except where steep banks occur.

Between 513 and 518 m a.s.l. (the extra 5 m to which ECNZ was granted access in 1992), shore profiles of the Tasman Delta are similar to those of the delta between 518 and 523 m a.s.l. (Fig. 2.10) but the substratum comprises a greater percentage of silt (85 - 100 % below 518 m a.s.l. *c.f.* 12 - 18 % above 518 m a.s.l.; Appendix 1).

Godley Delta, Lake Tekapo

The Godley Delta is 3 km wide (Fig. 2.1B). At high levels (*c.* 710 m a.s.l.), the lake edge is within 50 m of vegetated river flats across a third of the width of the delta. However, this vegetation is fairly low, and black stilts often forage close to the river flats. A large area of unvegetated, open habitat is available near the river mouth at all lake levels. As Lake Tekapo falls, it exposes large expanses of sand and silt in the middle of the delta and on its western side. On the east side of the delta, falling lake levels expose extensive mudflats (Figs. 2.11, 2.12). The mudflats provide abundant supplies of larval Chironomidae (non-biting midges), which appear to be a favoured food of black stilts (see Chapters 2, 10, 11).

Like the Tasman Delta, the Godley Delta is susceptible to the formation of gullies and steep banks at low lake levels (Fig. 2.13), yet the total amount of open habitat increases with declining lake levels. The most dramatic physical changes to black stilt habitat on the Godley Delta are caused by the weather. In cold conditions, a layer of ice (2 - 5 cm thick) can extend more than 50 m from the lake edge (Fig. 2.14), and prevent black stilts from foraging. High winds that bring about 'dust' storms on the delta (Fig. 2.15) also inhibit foraging activity.

Cass Delta, Lake Tekapo

The Cass Delta (Fig. 2.1C) is 10 km down the valley from the Godley Delta (at high lake levels). It is formed by two branches of the Cass River, each of which essentially forms its own delta. At low lake levels (< 707 m a.s.l.), these two deltas form a single entity three kilometres wide. The Cass River and Delta provide a large area of open, unvegetated habitat that is dissected by many small channels. The substratum is mainly cobbles in the river and sand and silt on the lower delta.

In the early 1980s, Pierce (1982a, 1982b, 1983, 1984b, 1986a, 1986b) studied several aspects of the biology of black stilts in the Cass Valley, including the Cass Delta. He considered (Pierce 1983) that a gradual decline in the level of Lake Tekapo during winter provided optimal foraging conditions for black stilts on the Cass Delta, but noted that, when the lake was unusually low in

1977 (702 m a.s.l. by mid-August), the substratum was "dried out and eroded", and black stilts left two weeks earlier than usual.

Hopkins Delta, Lake Ohau

The Hopkins Delta (Figs 2.1D, 2.16) is 3.5 km wide. Most of the delta is unsuitable for black stilts because it consists of densely vegetated areas of tall grasses and sedges behind a steep, narrow (1 - 10 m wide) beach. Black stilts on the Hopkins Delta forage in an area of open, unvegetated river bed habitat, near the mouth of the Hopkins River, and in several small bays (pers. obs.; Department of Conservation unpub. data). The substratum in the river bed comprises cobbles, shingle and sand, and some silt and mud. The physical nature of the habitat at the Hopkins Delta is affected little by changes in lake levels, because Lake Ohau is operated at a constant level.

Ahuriri Delta, Lake Benmore

Physical habitat provided by the Ahuriri Delta (Figs. 2.1E, 2.17) varies dramatically with lake level. At 361.2 m a.s.l., the level at which Lake Benmore is usually operated, most of the lake edge is overhung by willows, tall grasses and sedges (Fig. 2.18). A few patches of unvegetated habitat (up to *c.* 50m × 50 m) are available at the mouth of the Ahuriri River. However, if the lake is drawn down below *c.* 361.0 m a.s.l., the receding water exposes a large expanse of open, unvegetated habitat (*e.g.* > 60 ha at 360 m a.s.l.; Figs. 2.19, 2.20). On the south side of the Ahuriri Delta, the substratum comprises soft, organic mud; in the middle of the delta it consists of sand and silt, and on the north side, it comprises cobbles overlain by a thin (< 5 mm) layer of silt.

Tekapo/Ohau Delta, Lake Benmore

The Tekapo/Ohau Delta (Figs. 2.1F, 2.21) is formed where the Tekapo and Ohau Rivers flow into Lake Benmore. Prior to 1992, it was heavily vegetated with willows but during 1992 and 1993, willows were removed from the delta. It now provides more open habitat, although much of the delta is covered by tall grasses and regenerating willows. When Lake Benmore is full (*c.* 361.2 m a.s.l.), the lake margin at the Tekapo/Ohau Delta is a mosaic of cobbled river channels, mud, silt, sand and shingle, most of which is unvegetated. However, as the lake falls, substratum exposed at the lake edge is increasingly dominated by mud and silt.

Summary

With respect to physical characteristics, declining lake levels on the Tasman, Godley, and Cass Deltas appear to be beneficial in that they increase the area of habitat that is available to black stilts, but potentially detrimental because of vulnerability to erosion at low lake levels. The formation of gullies, and steep banks on these three deltas appears to depend on substratum particle size composition, river flows, wave action at the lake shore, and constancy of the lake level. The lake shore appears to be most prone to formation of steep banks when the lake is held at a constant level below *c.* 523 m a.s.l. (D. Murray, Department of Conservation, pers. comm.; pers. obs.).

The area of habitat available on the Hopkins Delta is essentially constant because Lake Ohau is operated at a constant level. Lake Benmore is also operated at a constant level, but has occasionally been drawn down 1 - 3 m below its minimum operating level. These drawdowns expose large expanses of open habitat on the Tekapo/Ohau and Ahuriri Deltas that appear to provide attractive habitats for black stilts. The response of black stilts to drawdowns of Lake Benmore, and the availability of food on these deltas at low lake levels are investigated in Chapter 5. The physical characteristics of these deltas are also described in more detail in Chapter 5.

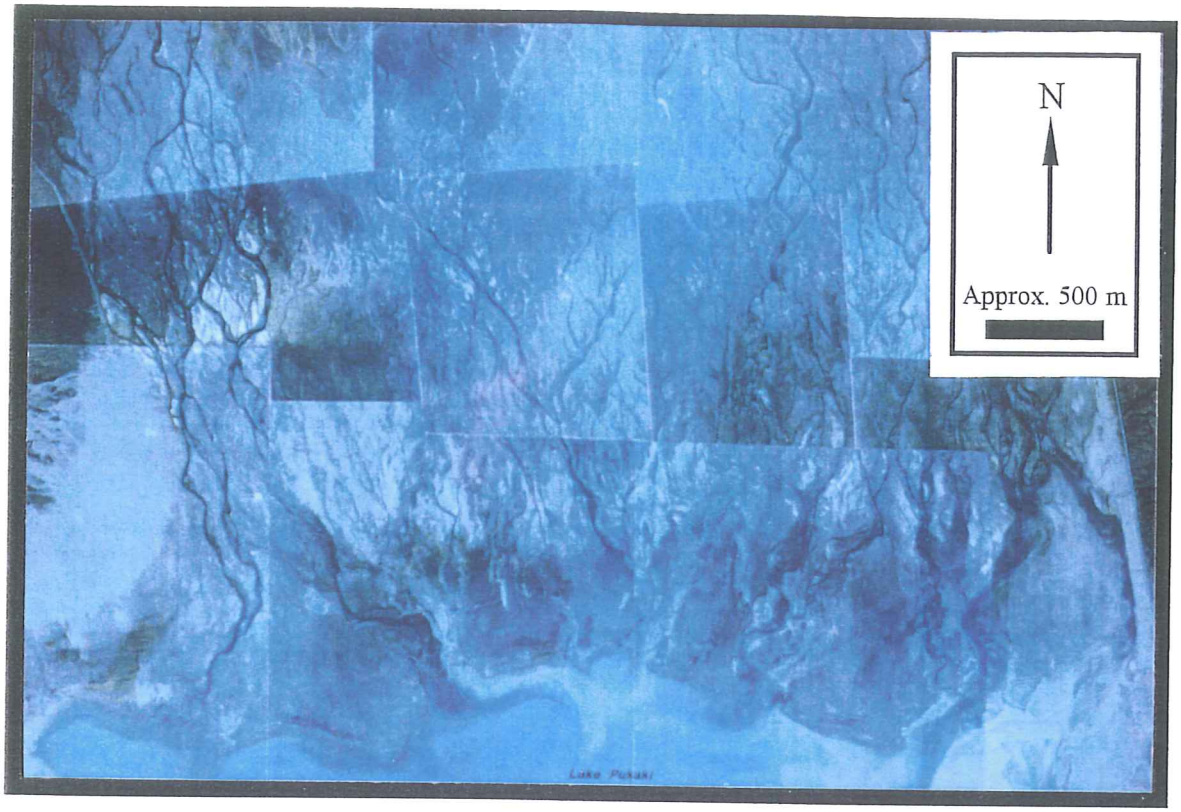


Figure 2.6. Composite aerial photograph of the Tasman Delta, taken when the level of Lake Pukaki was 519.84 m a.s.l. (5 October 1992). The lowest level recorded during the electricity shortage of 1992 was 519.10 m a.s.l. Note the change in substratum composition that occurs between 523 and 524 m a.s.l. as indicated by changes in shading. The dark substratum (below *c.* 523 m a.s.l.) consists of sand and silt; the pale substratum (above *c.* 524 m a.s.l.) comprises mainly cobbles, pebbles and gravels as defined by Cummins (1962).

Figure 2.7. View southwest from the Tasman Delta, 1 July 1993. Lake Pukaki is nearly 'full' (530.47 m a.s.l. see Table 2.1, Fig. 2.2, for operating levels). The pale substratum forming the bar on the right consists mainly of cobbles and large pebbles, whereas that in the foreground is mainly gravel (*c.f.* Figs. 2.8, 2.9).

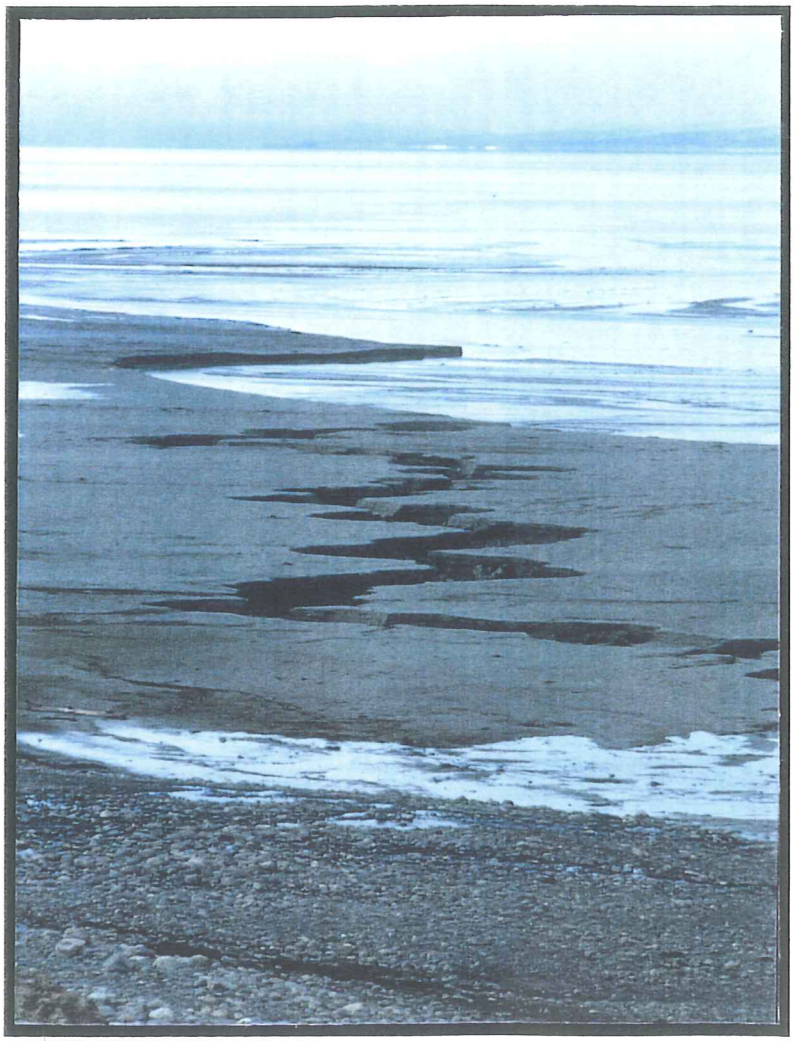


Figure 2.8 (above). View north from the Tasman Delta, 10 August 1992. Lake Pukaki is low (520.92 m a.s.l.). Note that the substratum consists of sand and silt, and that banks have begun to form at the lake edge. Note also the surface flow of water that is typical of much of the Tasman Delta at lake levels below 524 m a.s.l.

Figure 2.9 (left). Gully on the Tasman Delta, at low lake level (< 524 m a.s.l.; exact level and date unknown). The gully is *c.* 2 m wide Note the vertical banks at the lake edge.

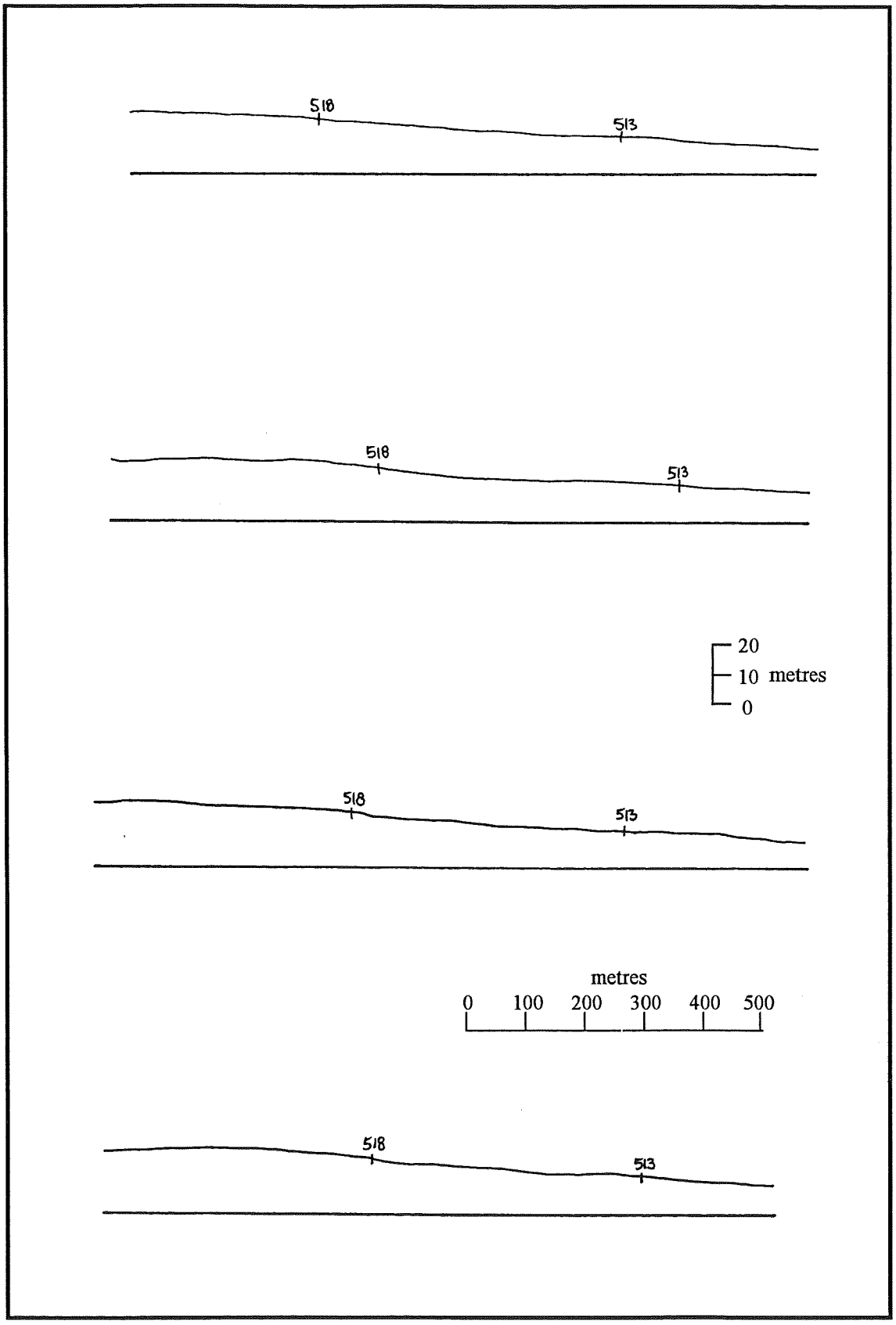


Figure 2.10. Longitudinal (*i.e.* north-south) shore profiles, at approximately 1000 m intervals, across the Tasman Delta. Taken from Works Consultancy Services drawing 6/1219/2 7644 sheet 2, with permission.

Figure 2.11. View west across the head of Lake Tekapo, 15 April 1994. The level of Lake Tekapo was 709.69 m a.s.l., which is close to its maximum control level (710.30 in April; Table 2.1). The lake edge was several hundred metres to the right of the point where this photograph was taken. Compare to Figure 2.12.

Figure 2.12. The Godley Delta, 29 July 1993, viewed from the same position as Figure 2.11 when the level of Lake Tekapo was 707.42 m a.s.l. Note the exposed mudflats in the foreground.

Figure 2.13. Bank formed by wave action at the edge of the Godley Delta. Photograph taken 22 June 1992, looking west. The level of Lake Tekapo was 703.70 m a.s.l.

Figure 2.14. Ice on the Godley Delta, 4 July 1993, when the level of Lake Tekapo was 708.92 m a.s.l. The view is to the east. The edge of the ice is more than 30 m from the shore, and the water at the edge is *c.* 25 cm deep - greater than the maximum depth to which black stilts can forage (18 cm).

Figure 2.15. Airborne silt and sand during high winds on the Godley Delta. Black stilts cannot forage in these conditions because they are battered by the sand and silt, and are blown off balance.

Figure 2.16. View west across the Hopkins Delta, 26 May 1993. The level of Lake Ohau was 519.9m a.s.l. Sand spits at the mouth of the Hopkins River can be seen in the middle-right of the photograph.

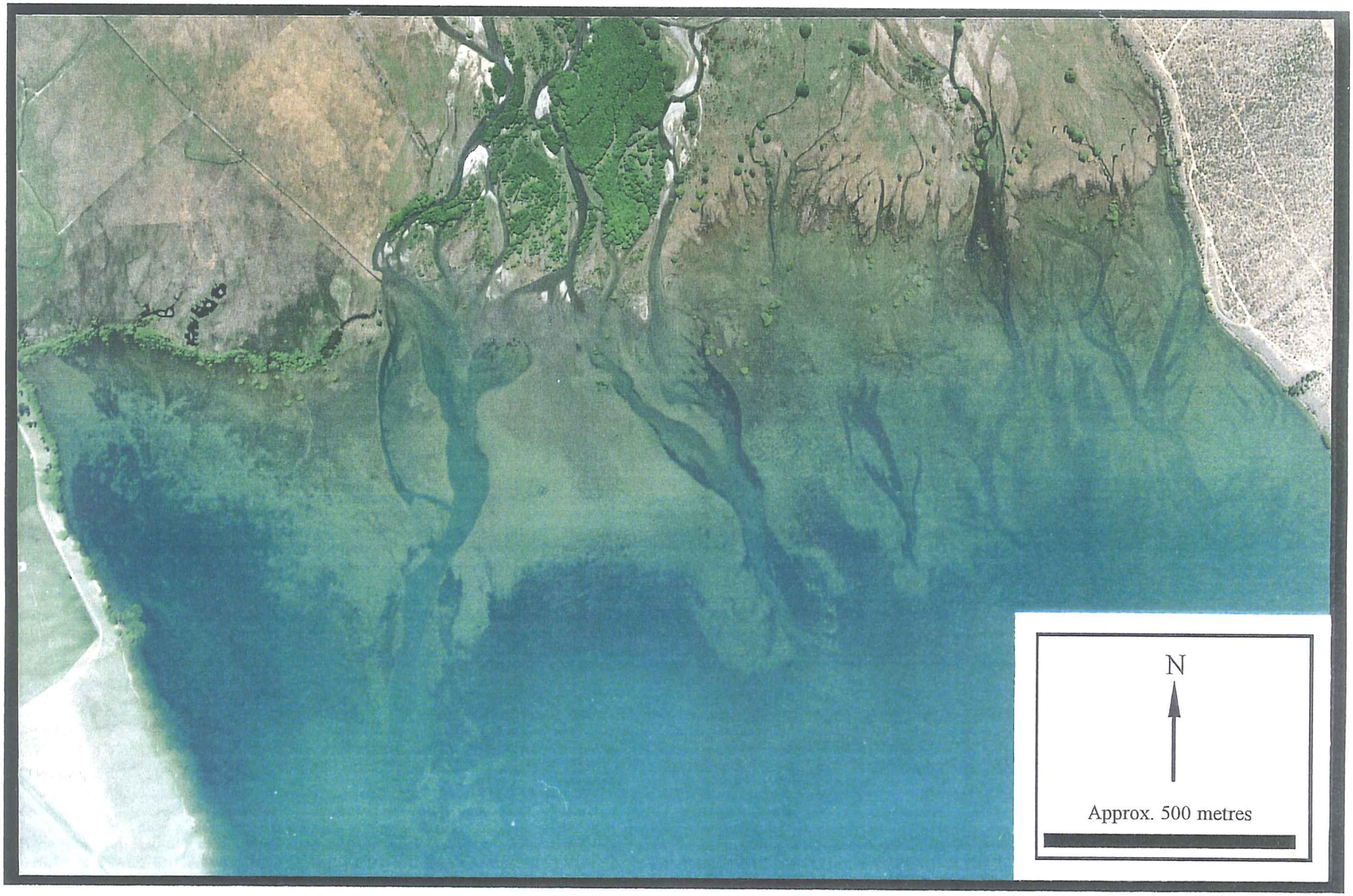


Figure 2.17. Aerial photograph of the Ahuriri Delta on 29 October 1993 when the level of Lake Benmore was 361.19 m a.s.l. The willows visible on the lower section of the Ahuriri River (the three main channels in the centre of the delta) were removed in 1994. Note mud and sand extending into the lake, particularly from the mouth of the Ahuriri River.

Figure 2.18. The Ahuriri Delta on 16 April 1994, when the level of Lake Benmore was 361.16 m a.s.l. The view is to the south, from the mouth of the Ahuriri River. Note the lack of open, unvegetated habitat that black stilts prefer (compare to Figs. 2.19, 2.20; the bush-filled gully in the background provides a reference point).

Figure 2.19. The Ahuriri Delta from the same position as Figure 2.18 but on 26 February 1994 when the level of Lake Benmore was 360.72 m a.s.l. (0.48 m lower than the normal level). At this lake level, sand and mudflats were exposed across the entire delta.

Figure 2.20. The Ahuriri Delta on 27 February 1994 when the level of Lake Benmore was 360.39 m a.s.l. Mud and sand flats extended 60 m from the lakeward edge of terrestrial vegetation (see Figs. 2.18, 2.19) to the water at this location.

Figure 2.21. View east across the Tekapo/Ohau Delta on 18 May 1993 when the level of Lake Benmore was 361.21 m a.s.l. The large channel on the left is the Tekapo River, and further left is the Tekapo Delta. The Ohau River is out of the photograph, on the right, but the Ohau Delta is visible in the centre and right. Lake Benmore is visible in the right background. Note that the Tekapo/Ohau Delta is less vegetated than the Ahuriri Delta (Figs. 2.17 - 2.20).

CHAPTER 3

Food supplies and foraging behaviour of black stilts on lake deltas

INTRODUCTION

During winter, black stilts spend most of their time foraging for aquatic invertebrates in shallow waters on the lake deltas (at lake margins and in streams that flow across the deltas; Pierce 1983; this thesis, Appendix 5). It is well known that the abundance and community composition of aquatic invertebrates at lake margins varies with changes in lake level (Moon 1935, Hynes 1961; Winter 1964; McLachlan 1970; Hunt and Jones 1972; Stark 1990; see also a review by Ward 1992), and one of the concerns during the 1992 electricity crisis was that low lake levels would affect black stilts by affecting the availability of their food supplies (Anon. 1992; Hughey 1992; James 1992; Murray 1992). Concern focussed on food supplies because the ability of birds other than black stilts to survive the winter, and to breed successfully during the following spring, has sometimes been considered to be related to the availability of winter food supplies (reviews by Goss-Custard 1984 and Puttick 1984; see also Cézilly *et al.* 1995 and references therein). However, it was not known how food resources used by black stilts would be affected by changes in the levels of the Upper Waitaki Lakes. Thus, the first aim of this study was to investigate how changes in levels of Lakes Benmore, Pukaki and Tekapo affected the taxonomic composition and biomass of aquatic invertebrates at black stilt foraging sites on lake deltas.

If the availability of food varies sufficiently to affect black stilts, it may be reflected in the foraging behaviour of the birds. Thus, foraging behaviour may provide an indicator of the quality of foraging habitat. The second aim of this study was to investigate whether the foraging behaviour of black stilts on lake deltas was affected by changes in lake levels.

METHODS

Foraging behaviour

The foraging behaviour and food supplies of black stilts were investigated on four of the six lake deltas described in Chapter 2: the Tasman, Godley, Ahuriri, and Tekapo/Ohau Deltas. Foraging behaviour and food supplies were measured at a range of lake levels, between July and August 1992, and March and August, 1993 and 1994. My study was restricted to those periods because lake deltas are used most extensively by black stilts at those times (Pierce 1983; DOC unpublished data). I began my study in July 1992, immediately after ECNZ decided to support an investigation into the potential influence of lake levels on black stilts. Hence, no observations were made from March to June 1992.

Lake deltas were surveyed as the levels of the lakes changed during winter by walking across each delta, roughly parallel to the lake edge, and searching for black stilts with 9 × 25 binoculars and a 25 × or 40 × spotting scope. When I encountered black stilts (which typically foraged in groups of 2 - 6), I measured feeding and searching rates (see below), and sampled aquatic invertebrates at the sites where they were foraging. 'Foraging sites' were defined as physically homogeneous areas in which one or more black stilts had been sighted foraging, and usually comprised a section of the lake shore, or the margins or mouths of shallow streams. Occasionally, several black stilts would be foraging in close proximity, but in distinctly different conditions (*e.g.* in flowing water at the edge of a stony riffle, and in still water in a sandy bay). In these cases I recognised each type of habitat as a different foraging site, and measured foraging behaviour and food supplies at each site separately.

I measured feeding rate (pecks per minute) and searching rate (steps per minute) by observing each black stilt with binoculars or a spotting scope, and counting the number of pecks, then steps, during two consecutive 30 second intervals (pecks and steps are defined in Appendix 3). If the bird under observation stopped foraging for more than five seconds during a 30 second observation period (*e.g.* to preen or roost, or to leave the water to defecate), the observation was abandoned. I continued measuring feeding and searching rates of black stilts at each site until I had made at least five observations of each bird, or until 90 minutes had passed, whichever occurred first. The 30 second measurements were averaged to yield mean foraging and searching rates for each black stilt, at each site, on each day ('bird means').

Habitat choice

Black stilt foraging sites were characterised by recording the estimated distance from each site to the nearest terrestrial vegetation, and to the lake edge.

Food supplies

After completing behavioural observations, I sampled aquatic invertebrates in the water column and substratum at each foraging site. Samples were taken from within a 0.1 m^2 stainless steel cylinder, at five haphazardly located points within each foraging site. Samples were taken by repeatedly passing a sieve (0.8 mm mesh, 200 mm diameter, 50 mm deep) through the water within the cylinder using one hand, while the water and substratum were stirred vigorously with the other hand. The sampling method, and method validation, is described in detail in Appendix 4. Samples were preserved in 10 % formalin and transported back to the laboratory. Invertebrates were removed from each sample, identified, counted, dried at 60° C, and weighed to the nearest milligram.

Data analysis

All analyses of feeding and searching rates were conducted on mean rates for each foraging site ('site means') because I saw no reason to assume that birds that were foraging together provided independent data. Site means were calculated as the mean of all 'bird means' (see above) at each site, on any particular day. Thus, all black stilts at a site carried the same weight in the calculation of that site mean, and all sites carried the same weight in the final analysis for that delta. I assumed that measurements made at different sites and on different days were independent within each delta. Data from each delta were analysed separately

I used least squares linear regression to investigate the relationships between foraging behaviour and food supplies of black stilts, and lake levels. The response variables were feeding rate, searching rate and invertebrate biomass. The predictor variable was 'standardized lake level'. Lake level was standardized by expressing it in terms of metres below the maximum control level (as prescribed for April), to facilitate between-lake comparisons of regression models. Maximum control levels for April are: Lake Pukaki, 532.0 m a.s.l.; Lake Tekapo, 710.0 m a.s.l.; Lake Benmore, 361.45 m a.s.l.; Lake Ohau, 520.25 m a.s.l. (also see Table 2.1). Residuals were inspected graphically for departures from the assumptions of regression, including curvilinear and

non-linear patterns. Heteroschedastic biomass data were $\log_{10}$-transformed, and residuals were re-examined. For the purposes of the log transformations, samples with mean biomass of 0 $g.m^{-2}$ were assigned the value 0.001 $g.m^{-2}$. Statistical significance was taken at $P \leq 0.05$. Analyses were conducted using the computer program STATISTIX (Siegel 1992).

RESULTS

Food supplies

Changes in lake levels were significantly related to mean ($\log_{10}$) invertebrate biomass at black stilt foraging sites on the Tasman and Ahuriri Deltas (Table 3.1), but the nature of the relationship differed markedly between the two deltas. On the Tasman Delta, mean ($\log_{10}$) invertebrate biomass declined significantly as the level of Lake Pukaki decreased, whereas on the Ahuriri Delta, mean ($\log_{10}$) invertebrate biomass increased with decreases in the level of Lake Benmore (Figs. 3.1a & b, 3.2). Mean invertebrate biomass at black stilt foraging sites was not related to lake level on the Tekapo/Ohau or Godley Deltas (Table 3.1; Figs. 3.1c & d, 3.2).

The overall mean invertebrate biomass per delta (*i.e.* the mean of foraging site means) ranged from 0.71 $g.m^{-2}$ on the Tasman Delta to 3.83 $g.m^{-2}$ on the Ahuriri Delta. However, the ranges of foraging site means on all deltas overlapped to a large extent (Fig. 3.3). Note that food supplies were sampled at as wide a range of lake levels as possible during this study. Thus, food supplies at typical ranges of lake levels are not necessarily represented by overall means and ranges. In particular, invertebrate biomass was highest in samples taken from the Ahuriri Delta at unusually low lake levels (< 359 m a.s.l.). However, these food supplies are rarely available because Lake Benmore is usually operated at a high level (*c.* 361.2 m a.s.l.).

Fifty-four aquatic invertebrate taxa occurred in samples taken from lake deltas, but most samples comprised high numbers of only one or two taxa, and very low numbers of several others (Appendix 6). To provide a broad indication of the composition of the fauna at black stilt foraging sites, those taxa that occurred at mean densities ≥ 1 per 0.1 m^{-2} sample, on at least one delta, are listed in Table 3.2 (a complete list of all taxa mentioned in this thesis is provided in Appendix 7). The dominant taxa in many samples were oligochaete worms and/or larval Chironomidae (non-biting midges; mainly *Chironomus zealandicus*). Mean oligochaete and chironomid densities, in all samples taken from each lake delta combined, ranged from 36.8 - 258.3 per 0.1 m^{-2} sample, and

Table 3.1. Results of regression analyses. The predictor variable was standardized lake level (see text for details). The response variables were mean invertebrate biomass, mean pecking rate, and mean stepping rate at each foraging site (N = number of sites). Note that analyses of invertebrate biomass in samples taken from the Tasman and Ahuriri Deltas were conducted on $\log_{10}$-transformed data.

Delta	r^2	P	N	Regression coefficients	
				Intercept	Standardized lake level
a) Invertebrate biomass					
Tasman	0.37	0.0008	27	0.071 ns	-0.149†
Ahuriri	0.70	<0.0001	20	-0.389†	0.384††
Godley	0.00	0.97	15	1.13*	-0.005 ns
Tekapo/Ohau	0.03	0.38	28	1.10*	0.163 ns
b) Pecks min^{-1}					
Tasman	0.13	0.061	27	28.8††	-1.11 ns
Ahuriri [a]	0.06	0.46	11	24.2*	4.46 ns
Ahuriri [b]	0.43	0.04	10	18.2**	5.70*
Godley	0.01	0.74	15	23.7††	-0.35 ns
Tekapo/Ohau	0.04	0.46	15	22.1*	2.29 ns
c) Steps min^{-1}					
Tasman	0.01	0.57	24	73.8††	0.83 ns
Ahuriri	0.19	0.18	11	53.3†	8.38 ns
Godley	0.21	0.10	14	90.6††	-3.24 ns
Tekapo/Ohau	0.13	0.19	15	85.9††	-6.06 ns

ns $P>0.05$, * $P<0.05$, ** $P<0.01$, † $P<0.001$, †† $P<0.0001$

[a] Analysis including outlier.

[b] Analysis excluding outlier.

from 37.1 - 224.0 per 0.1 m^{-2} sample, respectively (Table 3.1). However, samples taken from some sites contained high numbers of beetle larvae (Elmidae); waterboatmen, *Sigara* sp. (Corixidae); larvae of the caddisfly, *Oxyethira albiceps*, and six species of molluscs.

Molluscs were particularly abundant on the south side of the Ahuriri Delta, where samples were taken within dense stands of macrophytes (*Elodea canadensis*). High densities of molluscs in samples taken from the Ahuriri Delta were also recorded by Stark (1990). *Sigara* sp. appeared to be locally abundant in backwaters of the Hopkins Delta, in sheltered bays on the Tekapo/Ohau Delta, and among flooded terrestrial vegetation on the Godley Delta (at high lake levels). Samples

taken within large expanses of sand and silt contained few or no invertebrates. The fauna was particulary depauperate on the Tasman Delta and on the western side of the Godley Delta at low lake levels where the substratum comprised mainly sand and silt. Samples taken from sand and silt substrata on the Ahuriri and Tekapo/Ohau Deltas also contained few invertebrates.

Foraging behaviour

The relationships between feeding rates and lake levels broadly corresponded to the relationships between invertebrate biomass and lake levels (Table 3.1; and compare Figs. 3.1 and 3.4), but statistical models for feeding behaviour were weaker (lower r^2 and higher P values; Table 3.1) than those for food supplies. Thus, on the Tasman Delta, feeding rates declined with decreases in lake level, whereas on the Ahuriri Delta they increased with decreases in lake level. The model for the Tasman Delta was almost statistically significant ($P = 0.06$), and the model for the Ahuriri Delta was only statistically significant if an outlying datum was excluded from the analysis (Table 3.1; Fig. 3.4b). Feeding rates on the Godley and Tekapo/Ohau Deltas, like invertebrate biomass, did not vary significantly with lake level. Searching rates (not plotted) did not vary with lake level on any of the deltas (Table 3.1c). However, black stilts searched and fed very rapidly on one occasion when numerous chironomid larvae were washed up on the shore of the Godley Delta.

Habitat

When lake levels were high, black stilts on the Godley, Ahuriri and Tekapo/Ohau Deltas usually foraged at the lake edge. However, as lake levels declined, they tended to forage both at the lake edges, and on newly exposed, wet substrata up to 1600 m away (Fig. 3.5). In contrast, black stilts on the Tasman Delta often foraged away from the lake edge, even when lake levels were high (Fig. 3.5). This behaviour probably reflected the presence of a large amount of open habitat on the Tasman Delta at all lake levels (Chapter 2). In addition, black stilts often foraged in the Glentanner Stream (Fig. 2.1), where it meets the delta. The habitat provided by this stream is always accessible to black stilts, except when inundated at very high lake levels.

Although black stilts did not always follow the lake edge as lake levels declined, they still tended to move further down the delta. Thus, the distance from black stilt foraging sites to the nearest stable terrestrial vegetation increased significantly on the Tasman, Godley and Tekapo/Ohau Deltas (Table 3.3). Although black stilts on the Ahuriri Delta also tended to move further down the delta as lake levels declined, they usually foraged within 200 m of the southern shore of Lake Benmore, which is densely vegetated with willows (*Salix fragilis*; see Figs. 2.17 - 2.20).

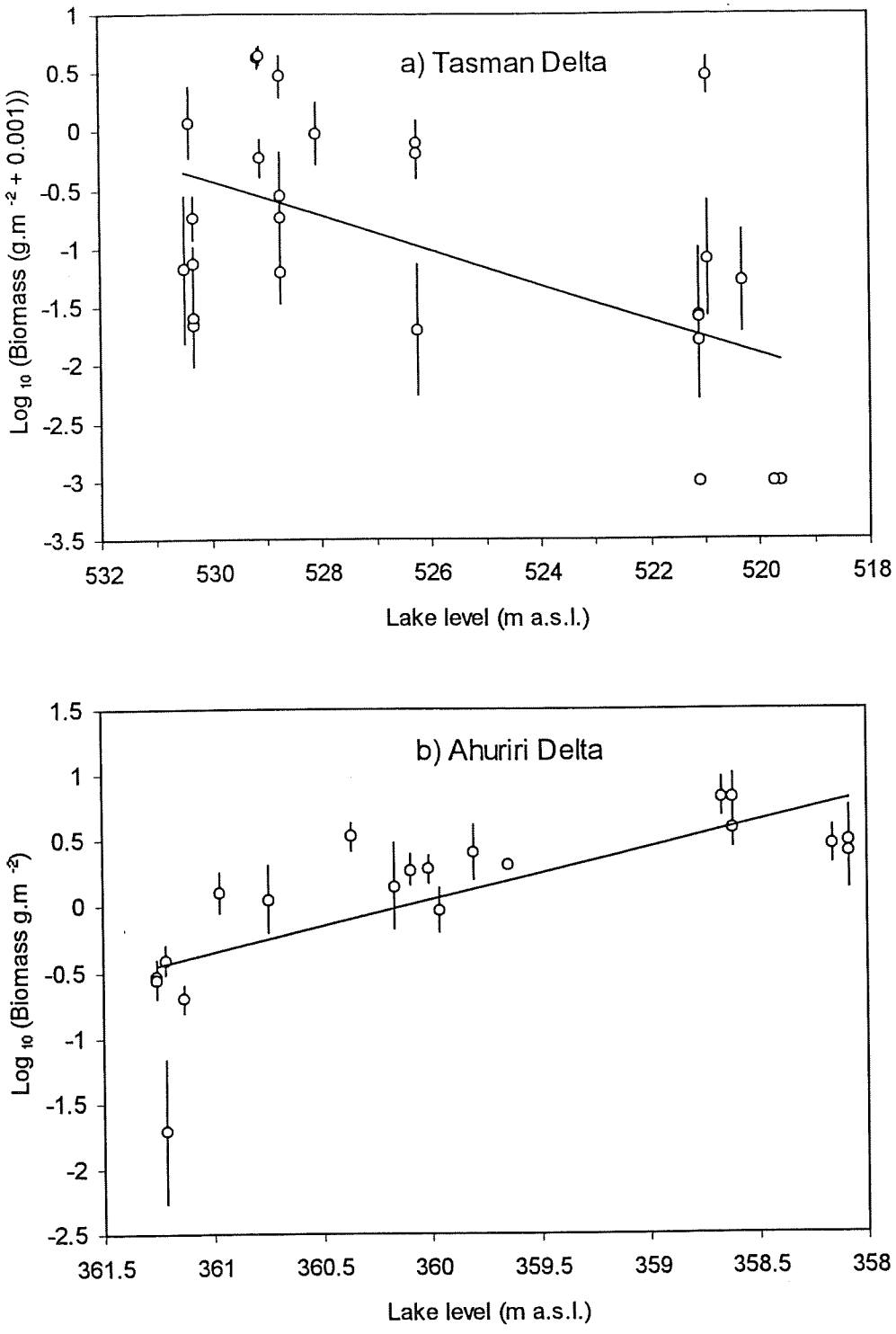


Figure 3.1. Relationships between lake levels and food supplies at black stilt foraging sites on the deltas of the Upper Waitaki Lakes. Each point represents mean (n = 5) biomass at a foraging site. Vertical bars show 1 SE (the standard errors of some means are too small to be visible in these graphs). Note that lake level decreases from left to right, and that scales differ among graphs.

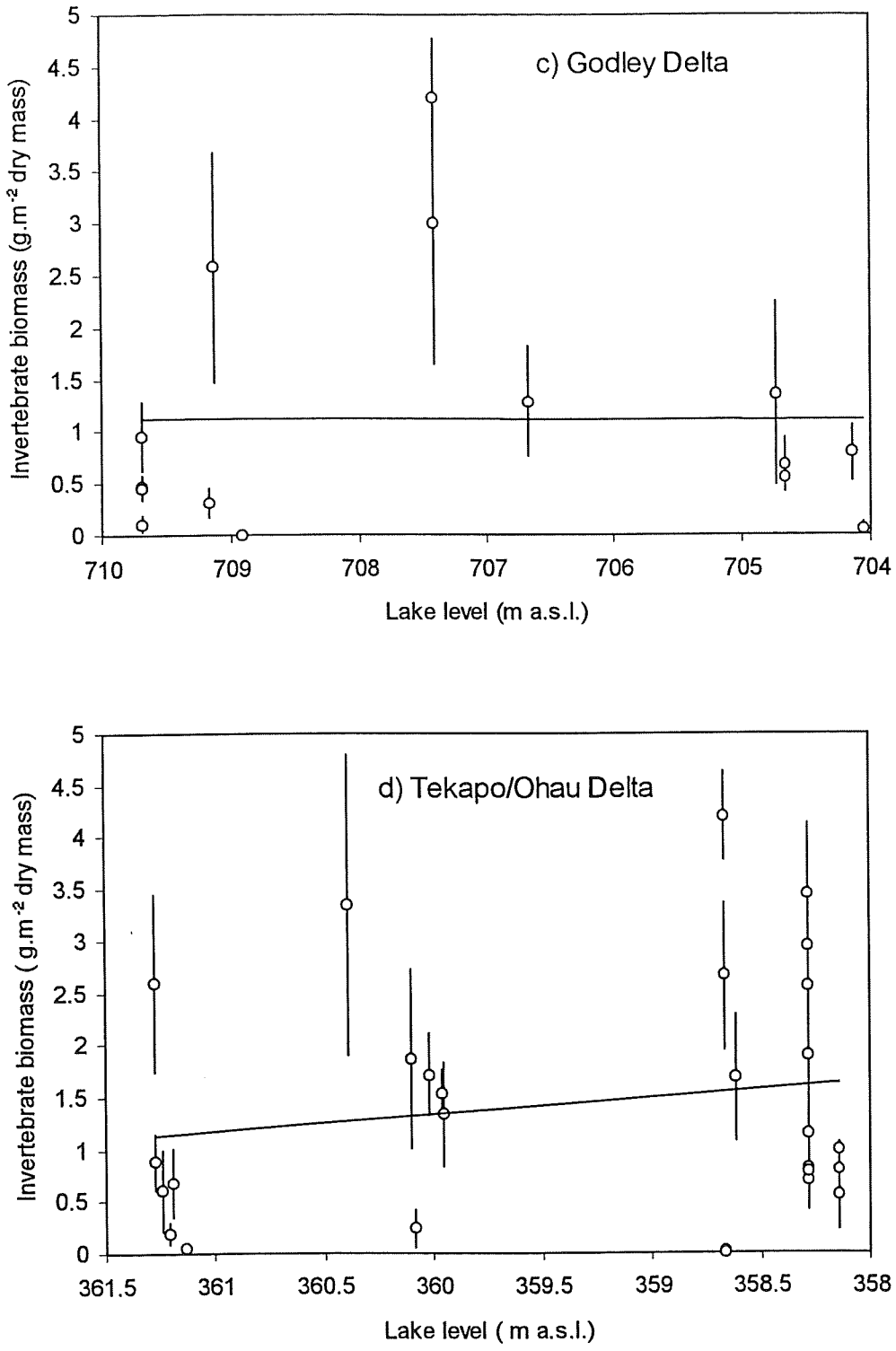


Figure 3.1. continued.

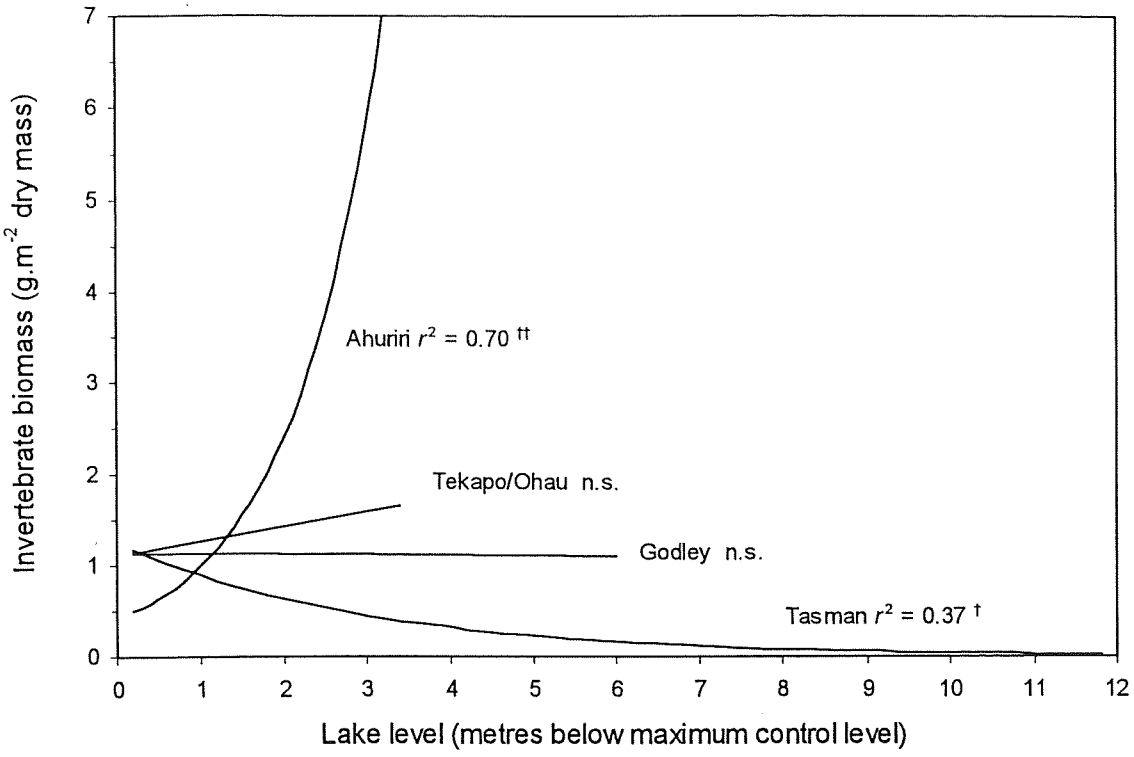


Figure 3.2. Comparison of the fitted models (presented separately in Fig. 3.1) of food supplies versus lake level, for the four deltas investigated in this study. Models developed from $\log_{10}$-transformed data have been back-transformed, and all lines are plotted against standardized lake level (see text and Table 3.1 for details). ns $P>0.05$, † $P<0.001$, †† $P<0.0001$.

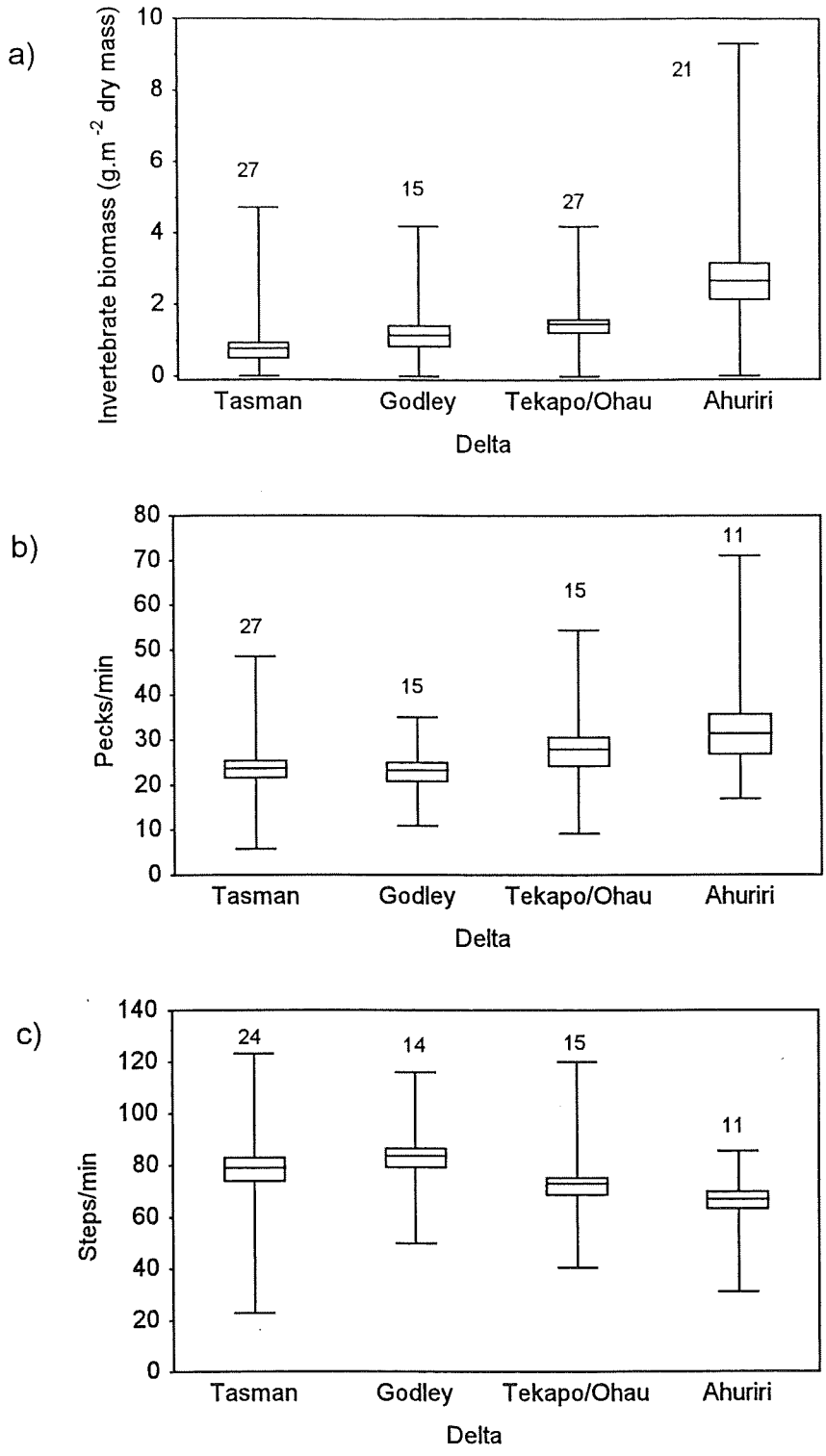


Figure 3.3. Black stilt food supplies (a), pecking rates (b) and stepping rates (c) on four lake deltas in the Upper Waitaki Basin. Boxes represent means (of site means; see text for details) ± 1 SE, and 'whiskers' show the ranges (of site means). The number of sites is shown above each box and whisker. Note that the data summarized in these plots are based on observations made over a wide range of lake levels, extending beyond the typical annual range.

Table 3.2. List of taxa that occurred at mean densities greater than 1 per 0.1 m^2 sample at one or more foraging sites. Values are grand means (*i.e.* means of site means; see text for details) for each delta. N = number of foraging sites.

Delta	Tasman	Godley	Ahuriri	Tekapo/Ohau
N	27	13	8	12
OLIGOCHAETA	36.79	126.23	258.33	127.35
DIPTERA				
Chironomidae	37.13	56.82	223.98	51.47
Tanypodinae	0.97	1.53	3.77	4.00
Aphrophila neozelandica	0.01	0.00	1.40	0.40
Eriopterini	0.36	3.20	0.00	0.60
Austrosimulium sp.	0.04	0.00	0.60	4.80
Muscidae	0.27	0.73	0.73	0.60
Diptera larva sp. 5	0.00	2.00	0.00	0.00
COLEOPTERA				
Berosus	0.20	1.20	0.00	0.90
Elmidae	0.43	2.20	0.90	11.00
Antiporus strigosulus	0.02	0.00	0.00	1.20
HEMIPTERA				
Sigara sp.	0.01	2.60	6.00	13.04
TRICHOPTERA				
Paroxyethira hendersoni	0.00	0.00	3.20	0.80
Oxyethira albiceps	1.30	0.80	4.67	2.70
Psilochorema nemorale	0.01	2.00	0.00	0.00
Neurochorema confusum	0.00	4.00	0.00	0.00
Pycnocentrodes sp.	0.46	1.10	0.20	1.40
Oecetis unicolor	0.02	0.00	2.00	0.00
Hudsonema amabilis	0.07	0.20	0.60	6.25
EPHEMEROPTERA				
Deleatidium spp.	8.24	3.16	0.00	0.20
PLECOPTERA				
Zelandobius confusus	1.18	0.00	0.00	0.00
Zelandobius sp.	0.08	1.20	0.00	0.00
Zelandobius furcillatus	8.27	3.20	0.00	0.00
MOLLUSCA				
Potamopyrgus antipodarum	0.50	0.87	108.80	0.40
Physa acuta	0.16	3.40	40.73	5.10
Lymnaea tomentosa	0.02	1.13	39.72	4.48
Lymnaea stagnalis	0.00	0.00	7.53	0.00
Gyraulus corinna	0.00	0.00	45.10	1.20
Sphaerium novaezelandiae	0.01	2.12	11.64	11.00
HIRUDINEA	0.00	0.00	1.10	0.00

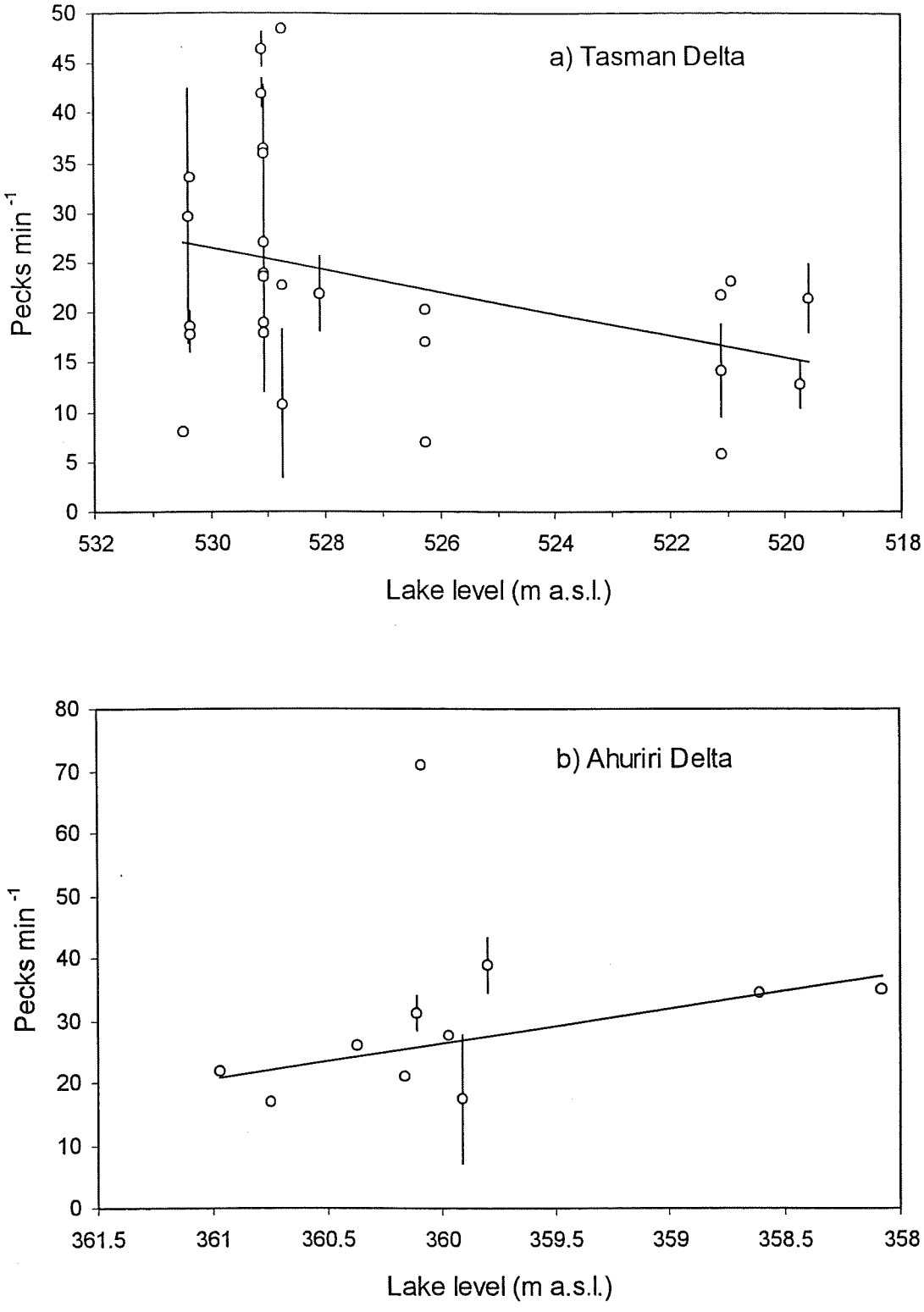
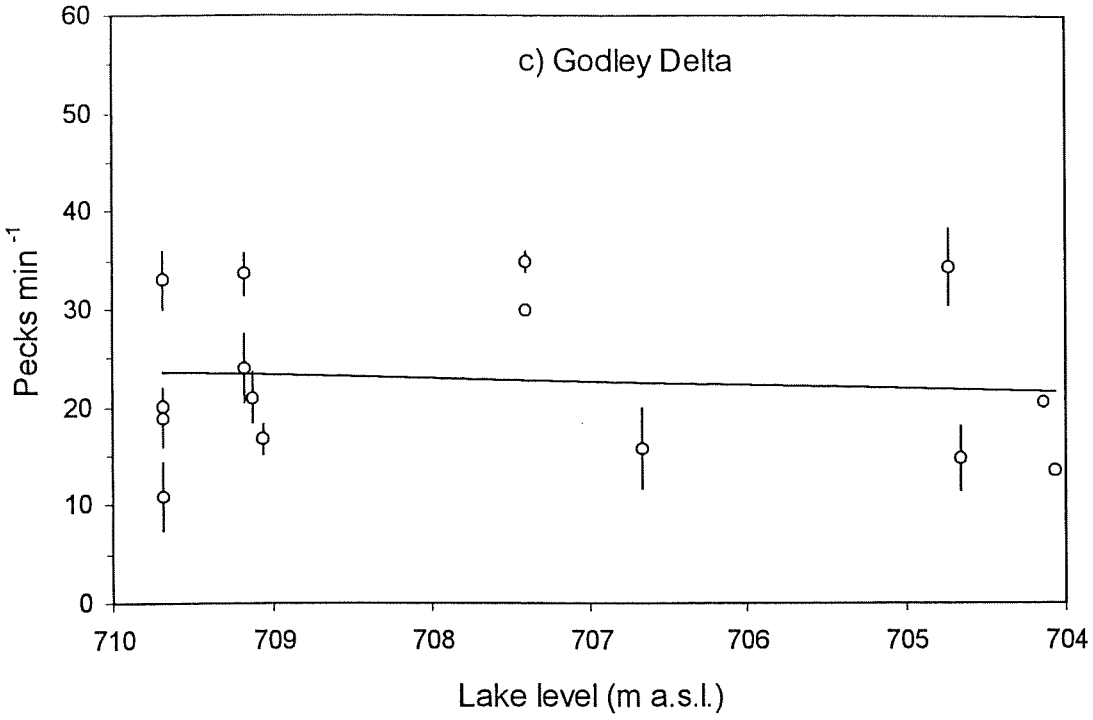


Figure 3.4. Relationships between lake levels and feeding rates of black stilts on the deltas of the Upper Waitaki Lakes. Each point represents the mean (n = 1 - 11) feeding rate at a foraging site. Vertical bars show 1 SE (except that observations based on a single bird have no standard error). Note that lake level decreases from left to right, and that scales differ among plots.



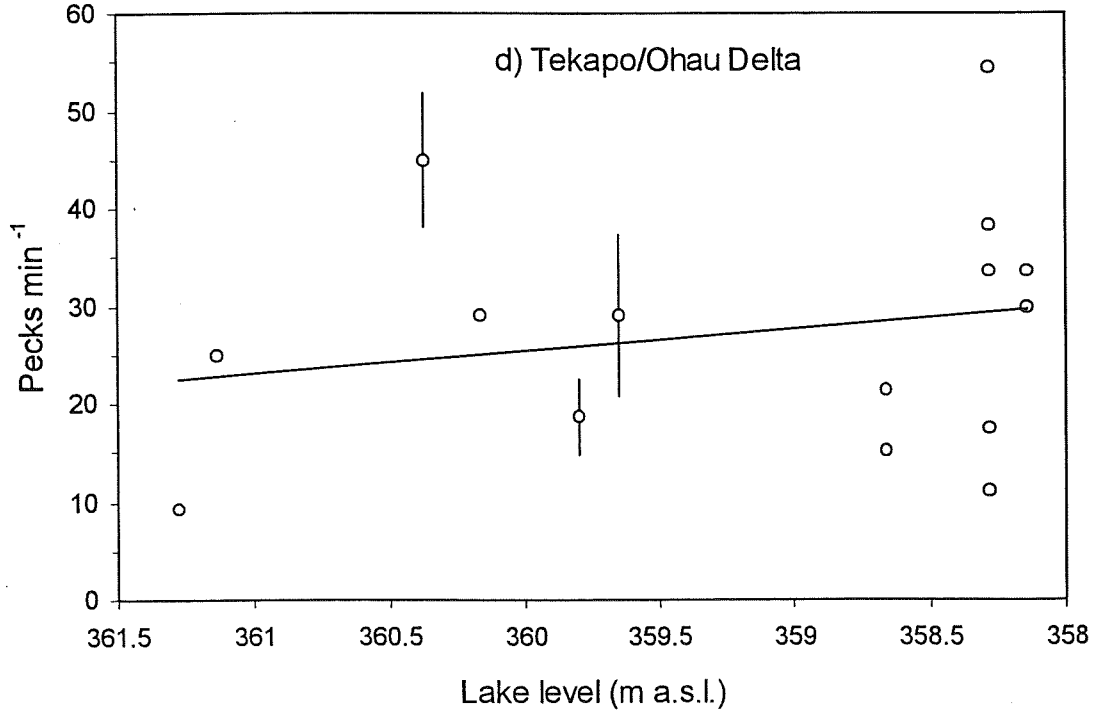


Figure 3.4. continued.

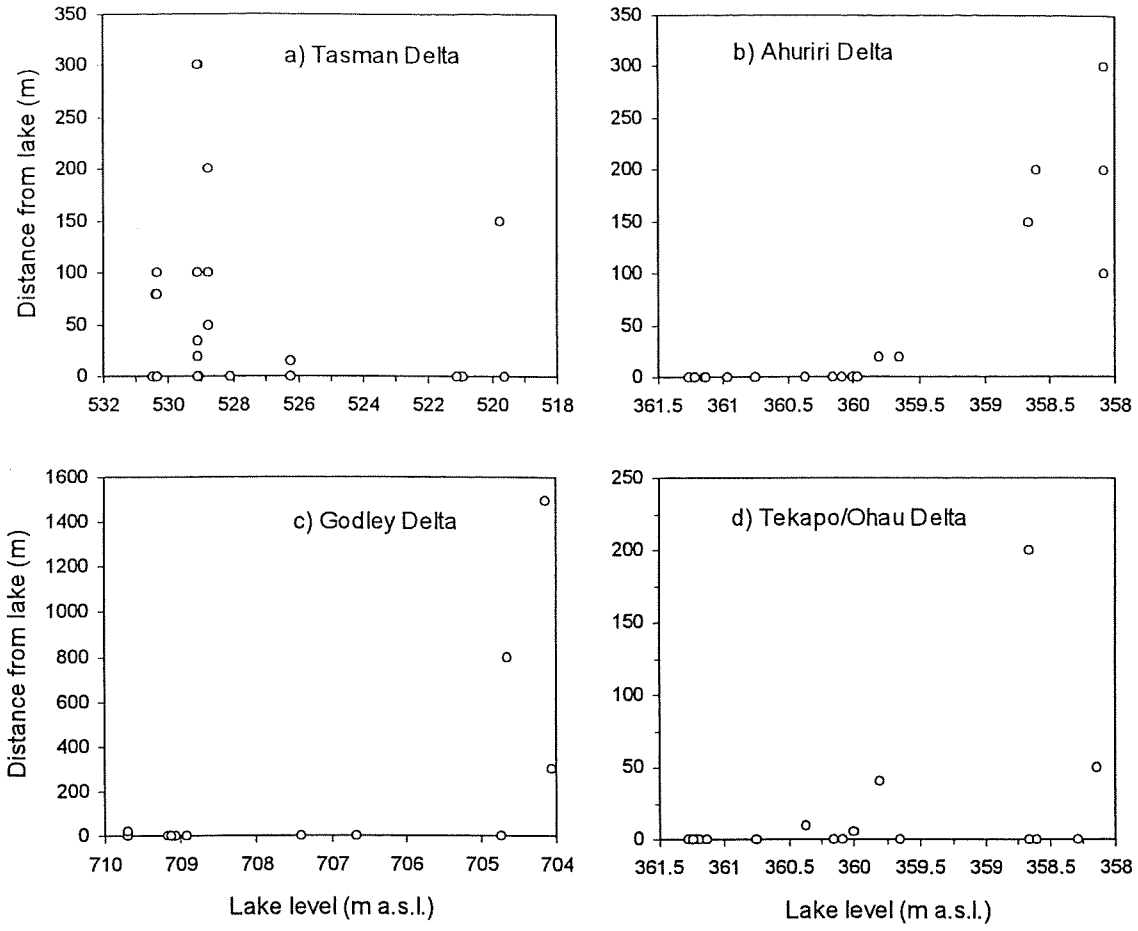


Figure 3.5. Distance from black stilt foraging sites to the lake edge at different lake levels. Note that lake level decreases from left to right, and that scales differ among plots.

Table 3.3. Correlation between lake level and distance from black stilt foraging sites to terrestrial vegetation on four lake deltas. N = number of foraging sites.

Delta	*r*	N	*P*
Tasman	-0.73	33	<0.0001
Ahuriri	-0.18	29	0.35
Godley	-0.71	16	0.002
Tekapo/Ohau	-0.60	29	0.0006

DISCUSSION

The results of my study show that declining lake levels can affect the food supplies and feeding rates of black stilts, but that these effects differ markedly among lake deltas. However, whether winter food supplies directly influence the viability of the black stilt population (*e.g. via* increased mortality or reduced nesting success as a result of poor nutrition) is unknown. Nevertheless, I have been able to identify the types of effects that could occur if the availability of food on lake deltas was a limiting factor. Thus, black stilts on the Ahuriri Delta *might* benefit from declining lake levels because abundant food supplies are exposed at these levels. Conversely, declining levels of Lake Pukaki *might* be detrimental to black stilts because food becomes very scarce at low lake levels, particulary at levels lower than 524 m a.s.l. In contrast to the Ahuriri and Tasman Deltas, invertebrate biomass did not vary with lake level on the Tekapo/Ohau or Godley Deltas and therefore could not in itself affect black stilts on these deltas. Regardless of whether the availability of food affects mortality or nesting success directly, it may influence the abundance of black stilts on lake deltas, and thus the probability of unpaired birds finding new mates. Relationships between black stilt abundance and lake levels, over the past 10 - 13 years, are investigated in Chapter 4.

A major concern during the electricity crisis of 1992 was that black stilts would be adversely affected by a reduction in food supplies as a result of extending the operating range of Lake Pukaki to include water stored between 513 and 518 m a.s.l. My results indicate that food is already extremely scarce (often absent from my samples) within the lower part (< *c.* 524 m a.s.l.) of the current operating range (518 - 532 or 532.5 m a.s.l.). It seems likely that the availability of food at the water's edge on the Tasman Delta, at levels below 518 m a.s.l., would be similar to that between 518 - 524 m a.s.l., *i.e.* extremely low. This is not to say that extending the operating range below 518 m a.s.l. would have no effect on the amount of food available to stilts foraging at the lake edge on the Tasman Delta. An extended operating range could bring forward the time when the lower reaches of the delta were exposed, and therefore increase the proportion of the winter during which food supplies at the lake edge were low. Even if this occurred, however, two questions would remain unanswered: First, would the large expanse of exposed habitat higher on the Tasman Delta compensate for potential changes in foraging conditions on the lower reaches? Second, is food a limiting factor on these deltas, anyway? Finding answers to these questions would require a substantial investment of resources - resources that may be better directed at mitigating already well-recognised threats, particularly degradation of breeding habitat, and predation on eggs and chicks.

CHAPTER 4

Use of lake deltas by black stilts: 1982 - 1994

INTRODUCTION

During winter most black stilts inhabit the deltas of the Upper Waitaki lakes, nearby tarns, ponds and rivers (Pierce 1982a, 1983). Black stilts are able to move easily between these habitats, and one of the ways in which they might respond to changes in lake levels is by moving on to or away from lake deltas. Thus, the abundance of black stilts on lake deltas may indicate the relative value of deltas as habitat for black stilts. However, the numbers of black stilts on lake deltas are potentially influenced by many other factors. For example, black stilt abundance on lake deltas is likely to vary with time of year, and total population size, regardless of lake level.

In this chapter I use Department of Conservation (DOC) and Wildlife Service records, and my own lake delta surveys of black stilts on lake deltas, to describe the abundance of black stilts on lake deltas over the past 10 - 13 years, and to investigate the relationship between black stilt abundance and lake level, total population size and time of year.

METHODS

The data analysed in this chapter were obtained by collating counts of black stilts made between 1985 and 1994 by the Department of Conservation and (before 1987) the Wildlife Service, and combining them with counts that I made during winter, 1992 - 1994 (data from 1982 counts on the Ahuriri Delta (Robertson *et al.* 1983) were also included). These data encompass a wide range of lake levels and climatic conditions. In particular, the data describe the numbers of black stilts on lake deltas on the few occasions, in addition to the 1992 power crisis, when any of the Upper Waitaki lakes had fallen to low levels. Lake level records were obtained from Workscorp, and total population size was estimated from the DOC database and unpublished internal reports.

Counts were undertaken by an observer who traversed the deltas by foot and/or boat, and searched for black stilts by eye, and with binoculars or a telescope. All black stilts that were sighted were

counted and their locations noted. The deltas are two to five kilometres wide, and delta surveys typically took several hours. The mean interval between surveys ranged from 9 to 23 days (Table 4.1). Most surveys were undertaken by one of five experienced observers, who used the same methods.

Only data from unambiguous records of delta surveys that were undertaken between 1 March and 31 August ('winter') each year were included in the analyses. The analyses were restricted to these months because outside this period the numbers of black stilts on lake deltas are strongly affected by seasonal movements to and from summer habitats (Pierce 1982a, 1983). Partial surveys of deltas were sometimes undertaken (especially of the Glentanner 'corner' of the Tasman Delta), but these were excluded from the analysis. The number of unambiguous winter records ranged from 67 for the Godley delta to 181 for the Tekapo/Ohau Delta (Table 4.1). For the purpose of these analyses, black stilts were defined as all stilts with plumage darker than Pierce's (1984b) 'node G', and included juveniles (*i.e.* birds less than one year old). The plumage 'node' of juvenile black stilts was ascertained from later records.

Multiple regression was used to develop models for black stilt abundance on each delta. Data for each of the six deltas were analysed separately. In addition to the separate analyses of each delta, counts of black stilts on the Godley and Cass Deltas of Lake Tekapo that were undertaken on the same day (as most were; Table 4.1) were combined and analysed together. An analysis of the total number of black stilts on one lake is useful because any evaluation of the effects of changing the

Table 4.1. A summary of the data collated from winter surveys of black stilts on Upper Waitaki lake deltas between 1985 and 1994 (and 1982 for the Ahuriri Delta).

Delta	Lake	Number of counts	Mean count (± SE)	Range of counts	Mean interval (days) between counts (± SE)	Range of intervals (days)
Godley	Tekapo	67	6.5 ± 0.5	0 - 21	21.8 ± 2.3	2 - 89
Cass	Tekapo	81	3.4 ± 0.4	0 - 13	17.2 ± 1.7	1 - 66
Godley & Cass	Tekapo	56	9.5 ± 0.6	0 - 22	23.4 ± 2.9	2 - 89
Tasman	Pukaki	96	6.3 ± 0.3	0 - 13	16.3 ± 1.8	1 - 82
Hopkins	Ohau	69	1.5 ± 0.1	0 - 4	23.0 ± 2.8	1 - 98
Ahuriri	Benmore	100	2.9 ± 0.5	0 - 21	15.2 ± 2.0	1 - 106
Tekapo/Ohau	Benmore	181	3.0 ± 0.3	0 - 19	9.1 ± 0.6	1 - 53

level of a lake should consider all black stilts on that lake. Although the Ahuriri and Tekapo/Ohau Deltas are both on Lake Benmore, they were rarely surveyed on the same day. Consequently, it was not possible to perform a combined analysis for all black stilts on the deltas of Lake Benmore. Forward stepwise selection was used to select the combination of predictor variables that produced the best model for each data set (the selection of variables was confirmed with backward stepwise selection).

The predictor variables investigated were: lake level (LEVEL), time of year (WEEK), $WEEK^2$, and total population size (POPN). WEEK was included because it seemed plausible that black stilt abundance might gradually increase or decrease during winter. It also seemed plausible that black stilt abundance might increase in early winter to a midwinter peak, and then fall away later in the winter. Such a rise and fall in abundance might be described approximately by a parabola, hence the inclusion of $WEEK^2$ as a predictor variable. To ensure that the parabola described by $-(WEEK^2)$ would take its maximum value in the middle of winter, when black stilts were potentially most abundant, the mean week of observation was assigned the value zero. Scaling WEEK in this way also improves the model selection procedure because it reduces intercorrelation between WEEK and $WEEK^2$ (Neter *et al.* 1985). POPN was included because it seemed likely that the number of black stilts on lake deltas would be influenced by the total number of black stilts present in the Upper Waitaki Basin.

Initially, I had intended to include two measures of change in lake level in the analysis, namely, the nett changes in lake level over 7 and 30 days prior to each count. I wanted to include these variables to investigate whether *change* in lake level, rather than lake level *per se* (LEVEL), was most closely associated with variation in black stilt abundance. However, preliminary correlation analyses (Table 4.2) showed that both these measures of change in lake level, and lake level *per se*

Table 4.2. Correlations between lake level *per se* (LEVEL) and nett change in lake level over 7 and 30 days prior to each black stilt count (LEV7 and LEV30, respectively).

Delta:	Godley	Cass	Godley & Cass	Tasman	Hopkins	Ahuriri	Tekapo/ Ohau
n	67	81	56	96	69	100	181
LEVEL vs. LEV7	0.15ns	0.36††	0.32*	0.23*	0.81††	0.61††	0.55††
LEVEL vs. LEV30	0.43††	0.57††	0.56††	0.27**	0.60††	0.86††	0.75††
LEV7 vs. LEV30	0.65††	0.61††	0.64††	0.69††	0.61††	0.74††	0.54††

* $P < 0.05$, ** $P < 0.01$, † $P < 0.001$, †† $P < 0.0001$.

were highly intercorrelated. Thus, lake level effectively also provides a measure of change in lake level, in these lakes. Measures of change in lake levels were therefore excluded from the model selection procedure. It needs to be emphasized, however, that any significant effects of lake level may be due to either lake level *per se* or to changes in lake level.

Analysis of the data was problematic because residuals of the data from models fitted for five of the seven sets of data were positively temporally autocorrelated (Durbin-Watson test; $P < 0.05$). Autocorrelated residuals have several potentially serious consequences. These include unreliability of the F-tests that are used to assess the statistical significance of the model, and underestimation of the standard errors of the regression coefficients, which are used to calculate prediction intervals (Neter *et al.* 1985). Autocorrelation of residuals can sometimes be eliminated by transformations of the data using first differences (Neter *et al.* 1985). However, this approach was unsuccessful with the data analysed here because it overcorrected the data, and caused negative autocorrelation. Therefore, to obtain non-autocorrelated data, I divided autocorrelated data sets in two by assigning every second datum to separate data sets. Each of these data sets was then reanalysed using stepwise regression as above, and residuals were again tested for autocorrelation. It was necessary to repeat this splitting process a second time for the Tekapo/Ohau Delta. Thus, between one and four statistically valid regressions were undertaken for each delta.

RESULTS

Black stilt abundance

Black stilts were most abundant on the Godley and Tasman Deltas, where means (± SE) of 6.5 ± 0.5 and 6.3 ± 0.3 black stilts, respectively, were sighted per month during the winters of 1985 - 1994 (Table 4.1). They were least abundant on the Hopkins and Ahuriri Deltas, where means of 1.5 ± 0.1 and 2.9 ± 0.5 black stilts per survey, respectively, were sighted. When the total numbers of black stilts on each lake are considered, Lake Tekapo can be seen to be the most important winter habitat; an average of 9.5 ± 0.6 black stilts were sighted on the Godley and Cass Deltas of this lake.

Although black stilts were usually scarce or absent on the Ahuriri Delta, two of the three highest counts were recorded there, during extreme drawdowns of Lake Benmore. In August 1982, and during the electricity crisis of 1992, the level of Lake Benmore fell below 358 m a.s.l., more than

three metres below the normal operating level of 361.2 m a.s.l. During both of these drawdowns, 21 black stilts were sighted on the Ahuriri Delta (see Chapter 5 for detailed descriptions of drawdowns of Lake Benmore). Twenty one black stilts were also sighted on the Godley Delta on 28 June 1989.

Regression analyses

Analyses of the split data sets yielded statistically significant models that explained between 11 % and 67 % of the variation in black stilt abundance on deltas of the Upper Waitaki lakes. The models obtained by splitting the data sets were similar to those obtained with the complete

Table 4.3. Results of regression analyses. The response variable was number of black stilts. 'All' indicates the models that were based on all data (see text for details). 'Half' or 'quarter' indicates the models that were based on subsets of the data. Significant values of the Durbin-Watson statistic, D, indicate positively autocorrelated residuals. Excl. shows that a variable was excluded from the model (see text).

						Regression coefficients				
Delta	Data	D	N	$r^2_{adj.}$	*P*	intercept	POPN	WEEK	WEEK^2	LEV
Godley	All	1.5*	67	0.32	<0.0001	-8.71*	0.21††	ns	-0.043††	ns
	Half	1.6ns	33	0.31	0.001	-7.78ns	0.20**	ns	-0.044**	ns
	Half	2.3ns	34	0.29	0.002	-9.8ns	0.23**	ns	-0.040*	ns
Cass	All	1.5**	81	0.10	0.002	-403.4**	ns	ns	ns	0.57**
	Half	2.0ns	41	0.14	0.010	-414.4*	ns	ns	ns	0.59**
	Half	2.2ns	40	0.05	0.079	ns	ns	ns	ns	ns
Godley & Cass	All	2.1ns	56	0.31	<0.0001	-9.05*	0.23†	0.24**	ns	ns
Tasman	All	1.4†	96	0.06	0.009	0.07ns	0.08**	ns	ns	ns
	Half	1.9ns	48	0.11	0.012	-2.37ns	0.11*	ns	ns	ns
	Half	1.7ns	48	0.01	0.26	ns	ns	ns	ns	ns
Tekapo/ Ohau	All	1.2††	181	0.49	<0.0001	1160.2††	ns	-0.28††	0.012††	-3.21††
	All	1.1††	181	0.46	<0.0001	1167.9††	ns	-0.27††	excl.	-3.23††
	Quarter	1.8ns	46	0.42	<0.0001	929.6†	ns	-0.24††	ns	-2.57†
	Quarter	1.5ns	45	0.57	<0.0001	1549.3††	ns	-0.26††	0.02*	ns
	Quarter	1.7ns	45	0.42	<0.0001	970.2**	ns	-0.32††	ns	-2.68**
	Quarter	1.7ns	45	0.45	<0.0001	1078.5††	ns	-0.24††	ns	-2.98††
Ahuriri	All	1.2††	100	0.64	<0.0001	1177.7††	ns	ns	ns	-3.26††
	Half	1.7ns	50	0.61	<0.0001	1167.5††	ns	ns	ns	-3.23††
	Half	2.2ns	50	0.67	<0.0001	1196.5††	ns	ns	ns	-3.31††
Hopkins	All	1.9ns	69	0.13	0.002	1.54††	ns	0.06*	ns	ns

ns $P > 0.05$, * $P < 0.05$, ** $P < 0.01$, † $P < 0.001$, †† $P < 0.0001$.

(autocorrelated) data sets (Table 4.3). Therefore, for presentation purposes, fitted lines and surfaces based on the complete data sets are plotted in Figures 4.1 - 4.7.

Godley Delta

The number of black stilts on the Godley Delta increased with population size, and tended to be greater in the middle of winter than at its beginning or end (Fig. 4.1). Together, POPN and $WEEK^2$ explained *c.* 30 % of the variation in black stilt abundance.

Cass Delta

Results for the Cass Delta suggest that the abundance of black stilts tends to be greater at higher lake levels, although numbers were highly variable at all levels (Fig. 4.2). Analysis of one half of the data resulted in a model in which LEVEL was significant and explained 14% of the variation in black stilt abundance. Analysis of the other half of the data produced no significant model, although LEVEL was the closest term to being selected ($P = 0.08$; Table 4.3).

Godley and Cass Deltas combined

The combined counts of all black stilts on Lake Tekapo indicate that black stilt abundance increases with population size and tends to be higher later in the winter (Fig. 4.3). Together, POPN and WEEK explained 31 % of the variation in black stilt abundance.

Tasman Delta

The numbers of black stilts on the Tasman Delta were highly variable at all times of year and at all lake levels investigated in this study (518.94 m a.s.l. - 532.58 m a.s.l.). Note however, that only five counts were undertaken when Lake Pukaki was lower than 524 m a.s.l., because the lake was rarely drawn down this low. No counts have been undertaken below 518 m a.s.l. because the lake level has not been lower than this since black stilts surveys began. A model based on one half of the data suggested that the number of black stilts sighted on the Tasman Delta increased slightly with population size (Fig. 4.4); however, this relationship was weak (regression coefficient = 0.11, $r^2_{adj.} = 0.11$; Table 4.3). The other half of the data yielded no significant model.

Hopkins Delta

Although numbers of black stilts on the Hopkins delta were always low, the analysis revealed a slight but significant trend for more birds to use the delta later in the winter (regression coefficient of WEEK = 0.06, Table 4.3; see also Fig. 4.5). This trend was in the same direction as that

observed for the Godley and Cass deltas combined, but in the opposite direction to that observed for the Tekapo/Ohau Delta.

Ahuriri Delta

In contrast to the above deltas, black stilt abundance on the Ahuriri Delta was strongly related to the level of Lake Benmore. The number of black stilts increased dramatically as Lake Benmore was lowered (Fig. 4.6), and LEVEL explained more than 60 % of the variation in black stilt abundance in both of the models based on half the data.

Tekapo/Ohau Delta

The number of black stilts on the Tekapo/Ohau Delta increased with decreasing levels of Lake Benmore and tended to be higher toward the end of winter (Table 4.3, Fig. 4.7). The model based on all data, and one of the models based on the quartered data included $WEEK^2$, but this variable explained less than an additional 4 % of the variation in both the models.

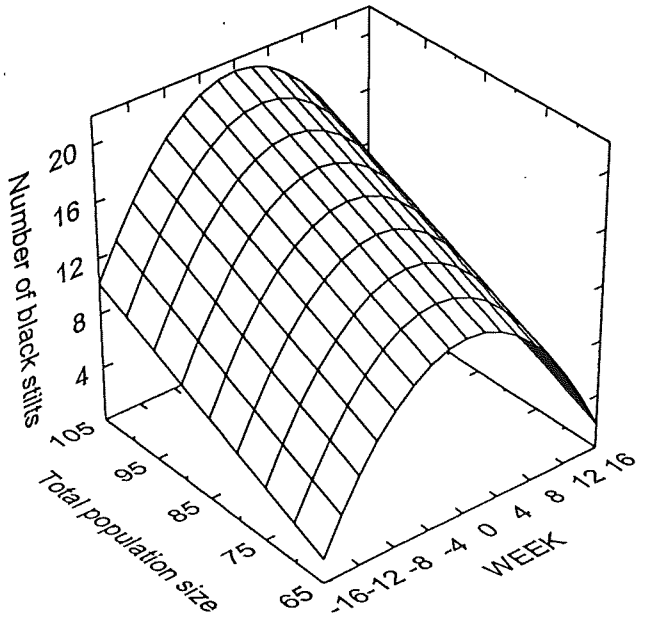


Figure 4.1. Expected abundance of black stilts on the Godley Delta of Lake Tekapo, in relation to total population size and week of year (WEEK). WEEK was scaled so that the mean week of observation (first week of June) took the value zero. The 'surface' represents the model fitted to the complete data set. Note, however, that analyses were also conducted on subsets of the data, because residuals of the model fitted to the complete data set were autocorrelated (see text and Table 4.3 for details).

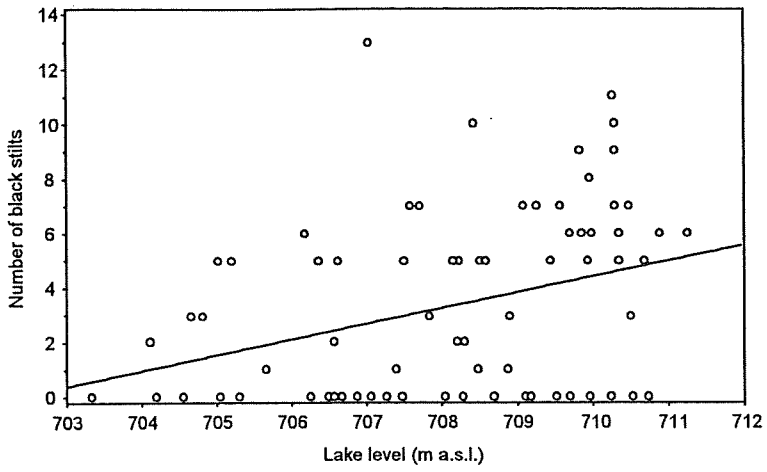


Figure 4.2. Relationship between the abundance of black stilts on the Cass Delta, and level of Lake Tekapo, during winters, 1985 - 1994. The line represents the model fitted to the complete data set. Note, however, that analyses were also conducted on subsets of the data, because residuals of the model fitted to the complete data set were autocorrelated (see Table 4.3 and text for details).

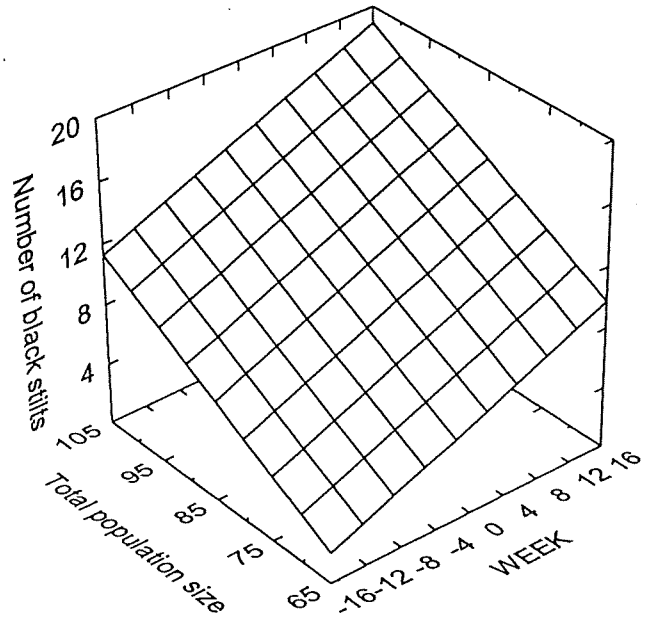


Figure 4.3. Expected abundance of black stilts on the Godley and Cass Deltas of Lake Tekapo combined, in relation to total population size and week of year (WEEK). Scaling and other conventions as in Figure 4.1.

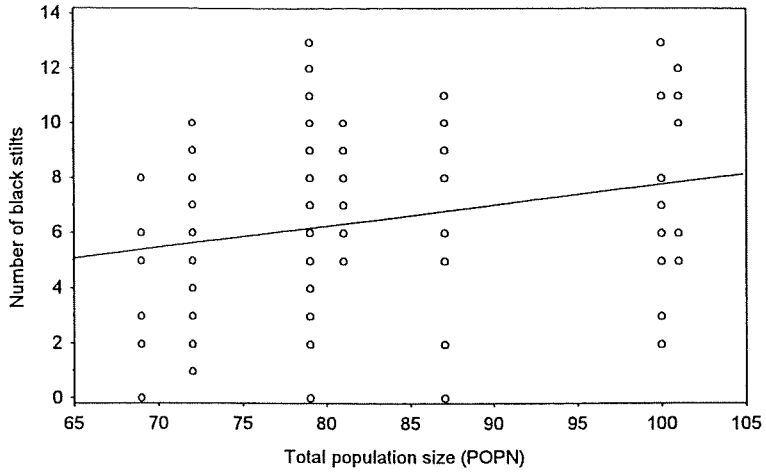


Figure 4.4. Relationship between the abundance of black stilts on the Tasman Delta, and total black stilt population size, during winters, 1985 - 1994. The line represents the model fitted to the complete data set. Note, however, that analyses were also conducted on subsets of the data, because residuals of the model fitted to the complete data set were autocorrelated (see Table 4.3 and text for details).

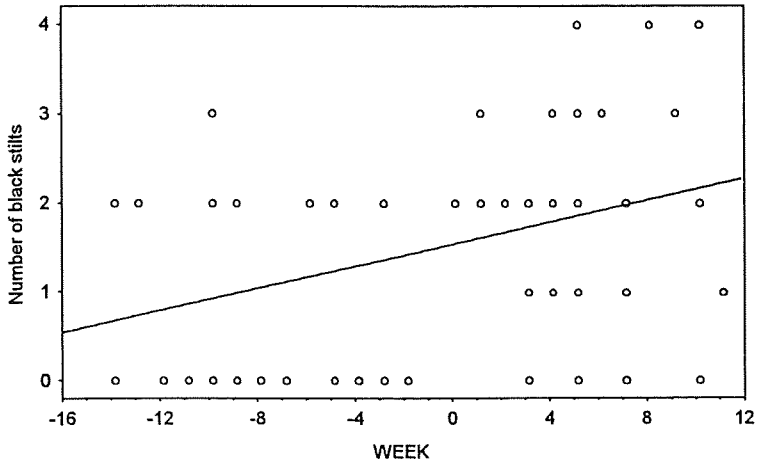


Figure 4.5. Relationship between the abundance of black stilts on the Hopkins Delta, and time of year (WEEK), during winters, 1985 - 1994. WEEK was scaled so that the mean week of observation (first week of June) took the value zero. The line represents the model fitted to the complete data set (see Table 4.3 and text for details).

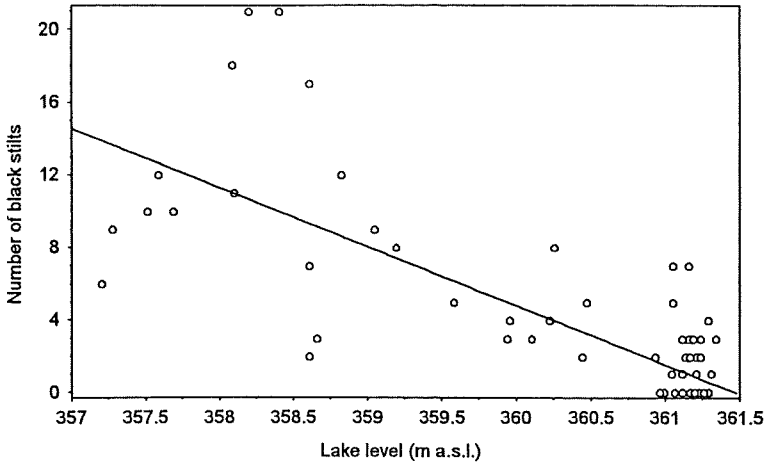


Figure 4.6. Relationship between the abundance of black stilts on the Ahuriri Delta, and level of Lake Benmore, during winters, 1982 and 1985 - 1994. The line represents the model fitted to the complete data set. Note, however, that analyses were also conducted on subsets of the data, because residuals of the model fitted to the complete data set were autocorrelated (see Table 4.3 and text for details).

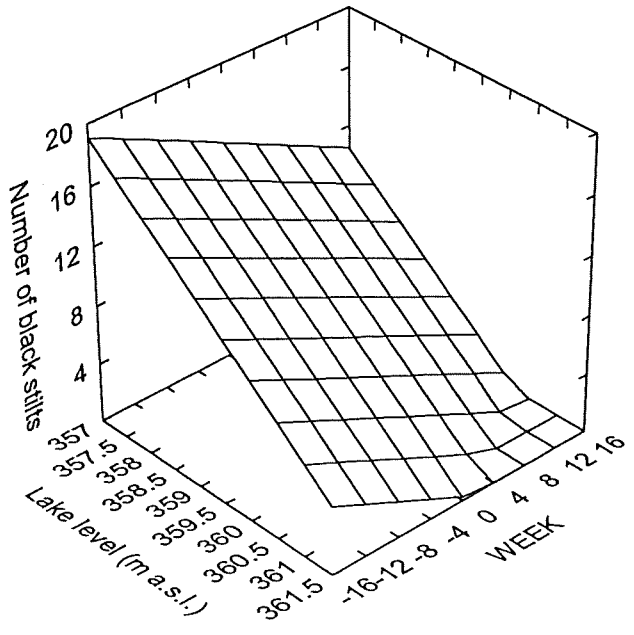


Figure 4.7. Expected abundance of black stilts on the Tekapo/Ohau Delta, in relation to the level of Lake Benmore, and week of year (WEEK). Scaling and other conventions as in Figure 4.1.

DISCUSSION

The objective of this study was to relate the numbers of black stilts on lake deltas in the Upper Waitaki Basin to four predictor variables: time of year (WEEK and $WEEK^2$), population size (POPN), and lake level (LEVEL). Statistically significant models were constructed for all seven data sets (six deltas, and the Godley and Cass Deltas combined). These models explained between 11 % and 67 % of the variation in black stilt abundance during the winters of 1982 - 1994 (and 1982 on the Ahuriri Delta). However, no variable consistently occurred in models for different deltas. Instead, the models suggest that different factors influence black stilt abundance on different lake deltas.

The main variable of interest from a management perspective is lake level, which varies as a result of hydroelectric generation. Lake level appeared to strongly influence numbers of black stilts on the Ahuriri Delta and Tekapo/Ohau Delta, but not on any other deltas. On the Ahuriri Delta and Tekapo/Ohau Delta more black stilts used the lake at low lake levels. The most likely reason for increased use of these deltas at low lake levels is that black stilts are attracted by the large areas of open unvegetated habitat, and the abundant and suitable food supplies that are exposed during drawdowns (Chapters 2, 3 and 5). In addition to lake level, time of year appeared to influence the numbers of black stilts on the Tekapo/Ohau Delta. The number of black stilts using this delta tended to decrease as winter progressed. Why this should be so is unknown, but may be related to seasonal variation in food supplies or availability of other habitats (*e.g.* ponds, flooded pasture, rivers). The strong influence of lake level on black stilt use of the Ahuriri Delta and Tekapo/Ohau Delta suggests that Lake Benmore could potentially be managed to benefit black stilts. In Chapter 5, I describe a more detailed study of the influence of drawdowns of Lake Benmore on black stilts, and discuss management options.

Whether lake levels influenced black stilt use of the Cass Delta is unclear because regression analyses of two subsets of the data were equivocal. However, even if black stilt abundance on this delta does vary with lake level, the effect appears to be weak. Lake level explained only 15 %, at most, of the variation in black stilt numbers on the Cass Delta. Furthermore, when numbers of black stilts on the Cass and Godley Deltas combined were considered, lake level no longer explained a significant proportion of the variation in black stilt abundance. Instead, population size and week of the year best described the total numbers of black stilts using Lake Tekapo. Thus, while changes in lake levels appear to affect the number of black stilts on the Cass Delta, they do not appear to influence the total number of black stilts using Lake Tekapo.

Black stilts are not affected by lake level *per se*. Rather, lake level is an indicator of the conditions that black stilts experience as a result of changes in lake levels (*e.g.* changes in the type and amount of habitat and food that is accessible). It is a convenient measure, and is relevant because public concern during the electricity crisis focussed on lake level *per se* (*e.g.* Anon. 1992, James 1992, letters to the editor in daily newspapers, May - June 1992), and because ECNZ's operating instructions are expressed principally in terms of lake level *per se*. Nevertheless, it is worth emphasizing that the mechanisms underlying the apparent 'effects' of lake levels are poorly understood, and the relationships described in this study may not hold under different water level regimes. For example, studies in New Zealand (Winter 1964; Stark 1990) and overseas (Moon 1935; Hynes 1961; McLachlan 1970; Hunt and Jones 1972) have shown that increases in water level fluctuations can alter the littoral invertebrate communities in lakes, sometimes dramatically (but see also James *et al.* 1995). In particular, the number of taxa, and the abundance of invertebrates, tend to decrease as a consequence of temperature extremes and desiccation during drawdowns (see review by Ward 1992). Lakes Pukaki and Tekapo already fluctuate widely. However, Lakes Ohau and Benmore are operated at relatively constant levels (see Chapter 2 for details). While drawdowns of Lake Benmore may have potential as a management technique (Chapter 5), the above-mentioned studies suggest that any increase in water level fluctuations are likely to adversely affect the littoral fauna. Greater fluctuations may also increase shoreline erosion and damage or kill littoral plants (Kirk and Henriques 1986; Mark 1987; Mark and Kirk 1987).

Numbers of black stilts on the Tasman Delta were not related to lake level or time of year, but analysis of one half of the data suggested that black stilt abundance increased with population size (the other half of the data yielded no significant model). However, at least 89 % of the variation in black stilt abundance on the Tasman Delta remained 'unexplained'. I must emphasize that my analysis was restricted to surveys of black stilts that were undertaken almost entirely within the upper 8 metres (> 524 m a.s.l.) of ECNZ's 14 - 14.5 metre operating range (518 - 532 or 532.5 m a.s.l.). The extent to which the results of this study can be used to infer the response of black stilts to levels of Lake Pukaki below 518 m a.s.l is discussed in Chapter 12, in the light of my research on the habitat, food supplies, and foraging behaviour of black stilts.

Although time of year was significant in the analyses of four of the seven data sets, no consistent trends emerged. In fact, the magnitudes and even the signs of the regression coefficients varied, and the linear (WEEK) and quadratic ($WEEK^2$) terms were either or both statistically significant, in different models. This inconsistency indicates that factors that influence the timing of movements of black stilts to and from lake deltas vary among deltas.

CHAPTER 5

Responses of black stilts to drawdowns of Lake Benmore

INTRODUCTION

Lake Benmore is usually operated at a constant level (*c.* 361.20 m a.s.l.) because its function is to provide a head of water for Benmore Power Station, rather than to provide storage. When Lake Benmore is 'full' (*i.e. c.* 361.20 m a.s.l.), few or no black stilts use the Ahuriri Delta (Chapter 4). However, in 1982, and during the 1992 electricity crisis, Lake Benmore was lowered more than three metres below its normal level. Apparently in response to these drawdowns, relatively large numbers of black stilts (up to 21) moved on to the Ahuriri Delta (Robertson *et al.* 1983; Murray 1992). (Lake Benmore was also lowered in 1984 and 1989, but I know of no records of black stilts on the Ahuriri Delta during those drawdowns.) In contrast, black stilts are usually present on the Tekapo/Ohau Delta even when Lake Benmore is full. Nevertheless, the number of black stilts on this delta also appeared to increase in response to the 1992 drawdown (Murray 1992). (Black stilts on the Tekapo/Ohau Delta were not surveyed during the 1982, 1984 or 1989 drawdowns.)

These records show that drawdowns of Lake Benmore can attract black stilts to the Ahuriri and Tekapo/Ohau Deltas. However, it is not clear how consistently black stilts respond to drawdowns, nor how their response is influenced by the magnitude, duration, and season of drawdown. A better understanding of these factors would contribute to our currently poor knowledge of black stilt habitat selection, and is likely to be applicable to the management of other black stilt habitats. An opportunity to increase our understanding of the effects of drawdowns of Lake Benmore on black stilts arose in February/March 1994. At that time, Lake Benmore was lowered by the Electricity Corporation of New Zealand (ECNZ) to facilitate the removal of willows from the Ahuriri River mouth (part of ongoing habitat restoration work on the Ahuriri River). The main objectives of the work described in this chapter were: 1) to record the numbers of black stilts on the Ahuriri and Tekapo/Ohau Deltas during this drawdown, and 2) to compare the numbers with those recorded during previous drawdowns of Lake Benmore.

During the 1992 drawdown, two factors appeared to make the Tekapo/Ohau and Ahuriri Deltas attractive to black stilts: 1) these deltas provided large areas of flat, unvegetated substratum, and

2) they provided abundant food supplies (*e.g.* larval Chironomidae, Oligochaeta, *Lymnaea* spp; Chapter 3). Open habitat appears to be a prerequisite for black stilts (Pierce 1982a, Robertson *et al.* 1983; pers. obs.), but how strongly food supply affects habitat selection by black stilts is poorly understood. In this chapter I also investigate the influence of food supply and habitat structure on black stilt foraging behaviour and habitat selection, on the Ahuriri and Tekapo/Ohau Deltas.

METHODS

Numbers of black stilts

ECNZ lowered Lake Benmore between 24 February and 20 March 1994. The lake level remained more than one metre below normal (*i.e.* < 360.20 m a.s.l.) for 19 days. Counts of black stilts on the Ahuriri and Tekapo Ohau Deltas were undertaken on as many days as possible before, during and after the drawdown. Counts were made by me, or one of two other experienced observers, using a standard survey method. Each delta was surveyed once on each sampling occasion, by following a standard route across the delta (roughly parallel to the lake edge), and searching for black stilts using binoculars and a 25 × telescope. All black stilts and dark hybrids (darker than Pierce's (1984b) Node 'F') were counted.

Food supply

Aquatic invertebrates were sampled, at the lake edge, on three transects on the Ahuriri Delta and two on the Tekapo/Ohau Delta (Fig. 5.1). The transects ran perpendicular to the high water shoreline, and were located at sites where black stilts had been observed foraging during previous drawdowns. Transects varied in length because the shore profile and thus the distance to the lake edge varied from site to site. Invertebrates in the water column and substratum were sampled from within a 0.1 m^2 cylinder, in 18 cm deep water, using the method described in Appendix 4. One cylinder sample was taken at each transect, on each visit to the deltas, during the period when the lake level was falling. Invertebrate samples were preserved in 10 % formalin, and transported to the laboratory, where they were removed from detritus, dried to constant mass at 60 °C, and weighed. Dry masses of molluscs and stony-cased caddisflies were corrected for shell and case weights by multiplying by 0.25, except that the mass of the gastropod, *Potamopyrgus*

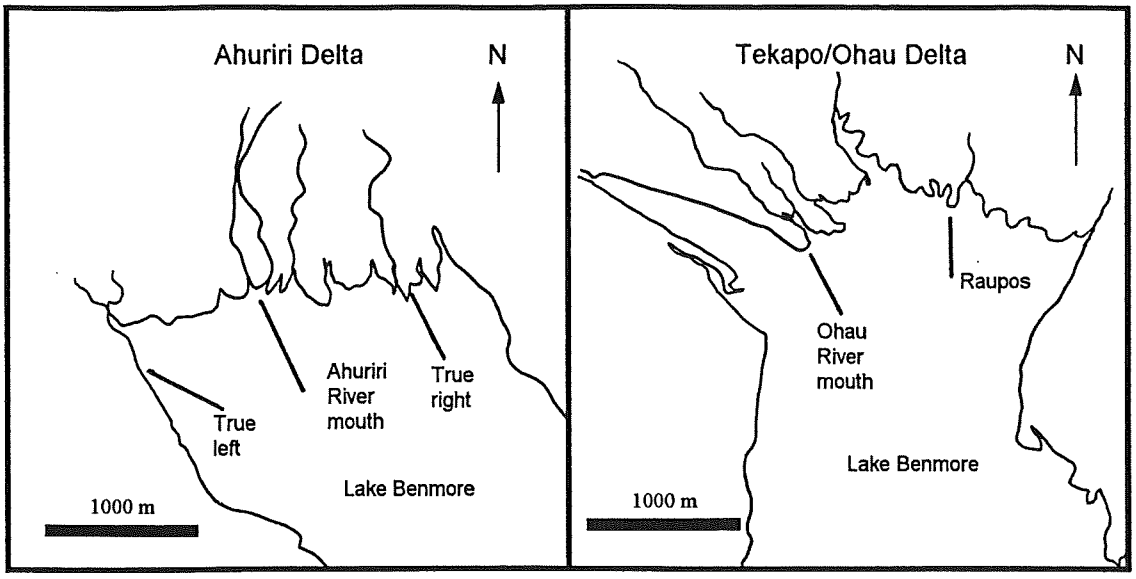


Figure 5.1. Locations of three transects (the straight lines) on the Ahuriri Delta and two transects on the Tekapo/Ohau Delta of Lake Benmore. Habitat measurements and invertebrate samples were taken along the transects as the lake was lowered during February/March 1994.

antipodarum, was multiplied by 0.10 (Michaelis 1974). Conversion factors for all other species were determined by weighing subsamples of animals.

Ordinary least squares regression was used to test whether invertebrate biomass along each transect was linearly related to lake level. Residuals were inspected graphically for departures from the assumptions of regression. No transformations of data were necessary.

Foraging behaviour

Feeding and searching rates, at different lake levels, were measured by counting the number of pecks and steps, respectively, during 30 second periods (refer to Appendix 3 and Chapter 3 for details of the method). One to three black stilts were sampled on the Ahuriri Delta, on five days during the drawdown. One to ten black stilts were sampled on the Tekapo/Ohau Delta, on nine days. Fewer foraging observations than counts were made, on each delta, because black stilts were not always foraging when sighted. One mean feeding rate was calculated for all black stilts at each foraging site on each day, as in Chapter 3.

Physical habitat

I characterized the physical habitat at each transect on each delta survey (and therefore at a range of lake levels) in two ways. First, to provide an indication of the openness of the delta, I estimated the distance from the water's edge to permanent vegetation. Second, to provide an indication of the extent of the shallows in which black stilts could forage, I measured the distance from the water's edge to 18 cm deep water.

RESULTS AND DISCUSSION

Numbers of black stilts

As soon as ECNZ began to lower Lake Benmore in February 1994, three black stilts were sighted on the Ahuriri Delta. No black stilts had been sighted on three previous occasions in January and February prior to the drawdown (Fig. 5.2). During all nine delta surveys undertaken during the drawdown (defined as levels < 361 m a.s.l.), three or four black stilts were sighted on the Ahuriri Delta. When Lake Benmore was raised again, no black stilts were sighted on the delta. Similar patterns were reported in 1982 and 1992 (Fig. 5.2). In contrast to the 1994 drawdown, however, up to 21 black stilts were sighted on the Ahuriri Delta during the 1982 and 1992 drawdowns.

Lower numbers of black stilts may have used the Ahuriri Delta in 1994 than in 1982 and 1992 for at least three reasons. First, in 1994, Lake Benmore was only drawn down to 359.9 m a.s.l., a level more than two metres higher than the drawdowns of 1982 and 1992. The area of exposed substratum was therefore much smaller in 1994 than in 1982 and 1992. Second, the 1994 drawdown lasted only one month whereas the previous drawdowns had lasted three to four months. Maximum numbers of black stilts were not recorded until 30 and 44 days respectively after the 1982 and 1992 drawdowns began. Those delays suggests that black stilts in the vicinity of the Ahuriri Delta may have had insufficient time to respond to the 1994 drawdown. Finally, the 1994 drawdown occurred in early autumn when black stilts may still have been widely dispersed. In contrast, the previous drawdowns occurred in late winter or early spring, the times when black stilts were most likely to be present on lake deltas (Pierce 1982a, 1983).

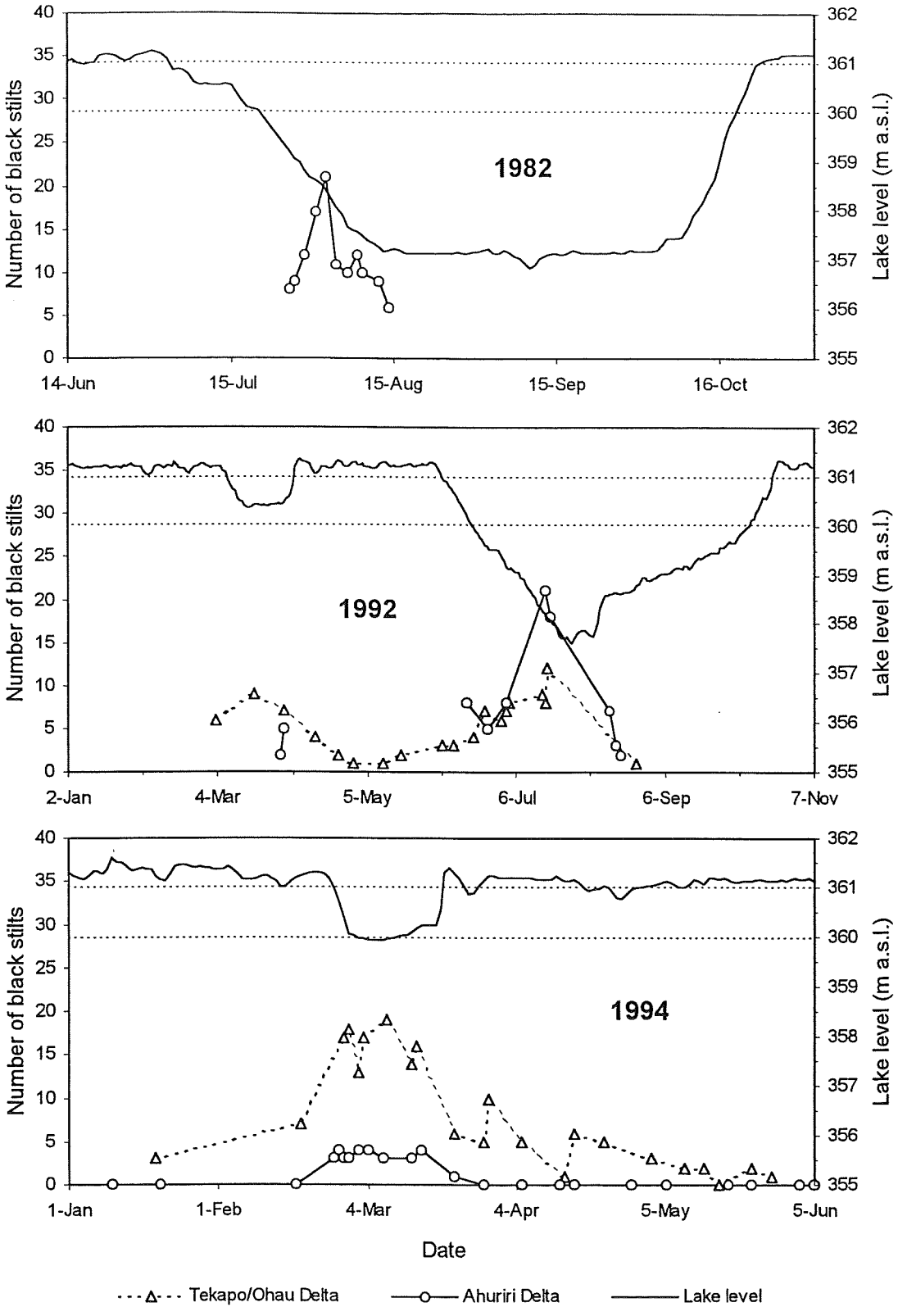


Figure 5.2. Numbers of black stilts counted on the Ahuriri and Tekapo/Ohau Deltas during three drawdowns of Lake Benmore below 360 m a.s.l., between 1982 and 1994. The 1982 data are taken from Robertson *et al.* (1983), with permission. For reference, the dotted lines show 360 and 361 m a.s.l. Note the apparent response of black stilts to a small drawdown in March/April 1992.

On the Tekapo/Ohau Delta 13 - 19 black stilts were sighted during the 1994 drawdown, compared to 0 - 10 before or after the drawdown, and up to 12 during the 1992 drawdown (Fig. 5.2). The large increase in the number of black stilts, and the close association of the increase with low lake levels suggests that black stilts in the vicinity of the Tekapo/Ohau Delta responded strongly to the 1994 drawdown of Lake Benmore.

However, it is also possible that the observed response was caused by a combination of two other events. Thus, most of the black stilts sighted on the Tekapo/Ohau Delta were eight month old birds that had been released from the nearby Department of Conservation captive rearing aviary in September 1993, five months before the drawdown. In previous years, juveniles released from the aviaries have found their way to the Tekapo/Ohau Delta over several months (Adams 1995). The arrival of the recently released juveniles on the Tekapo/Ohau Delta at the beginning of the 1994 drawdown may have been coincidental. Similarly, the suddenly decline in numbers of black stilts on the Tekapo/Ohau Delta coincided both with the raising of the lake, and with large floods. Black stilts may have left the Tekapo/Ohau Delta in response to a deterioration in foraging conditions associated with the floods (high flows on the delta, turbid water), and/or in response to the raising of Lake Benmore.

Despite these confounding factors, the observed pattern in black stilt numbers is at least consistent with the contention that black stilts are attracted to the Tekapo/Ohau Delta when Lake Benmore is lowered. Support for this contention was also provided by an increase in the number of black stilts on the Tekapo/Ohau Delta when lake levels declined slightly in March/April 1992 (Fig. 5.2).

Food supplies

Oligochaeta, Chironomidae and Mollusca contributed almost all the aquatic invertebrate biomass in samples taken from the Ahuriri Delta, as found also by Stark (1990). The same taxa strongly dominated invertebrate biomass in most samples taken from the Tekapo/Ohau Delta. However, a few samples from stony substrata at the Ohau River mouth consisted mainly of non-chironomid insect larvae, including the beetles, *Berosus* sp. and Elmidae, and the mayfly, *Deleatidium* sp.

Invertebrate biomass ranged from 0.19 $g.m^{-2}$ to 5.0 $g.m^{-2}$ in samples taken from the Ahuriri Delta and from 0 $g.m^{-2}$ to 4.79 $g.m^{-2}$ in samples taken from the Tekapo/Ohau Delta (Fig. 5.3). These values are moderate to high in comparison to biomass in samples taken from other deltas, nest

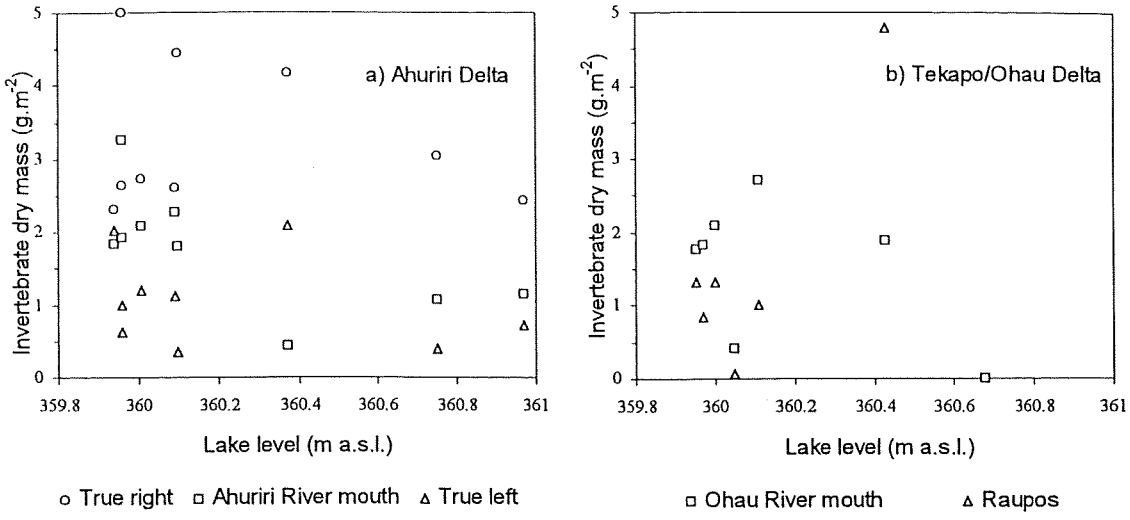


Figure 5.3. Invertebrate biomass in samples taken from three transects on the Ahuriri Delta and from two transects on the Tekapo/Ohau Delta of Lake Benmore, during a drawdown in February - March 1994.

sites, and wetlands (see Chapters 3, and 6 - 9; note, however, that biomass differed in samples from those sites partly because they were taken at different times of year).

No consistent relationship between invertebrate biomass and lake level was evident at the range of lake levels investigated in this study. Invertebrate biomass was not significantly related to lake level on three of the five transects (the Ohau River mouth, and the true left and true right of the Ahuriri Delta; linear regression, $P > 0.05$). A significant decrease with decreasing lake level was found on the 'raupos' transect on the Tekapo/Ohau Delta (Fig. 5.1), but this relationship disappeared when an outlying datum was excluded from the analysis (linear regression, $r^2 = 0.77$, $P = 0.02$ with outlier, $r^2 = 0.14$, $P = 0.54$ without outlier). At the Ahuriri River mouth, however, invertebrate biomass increased with a decrease in lake level ($r^2 = 0.52$, $P = 0.02$). A similar trend was revealed by more extensive sampling of the Ahuriri Delta, undertaken as part of the work reported in Chapter 3 ($r^2_{adj.} = 0.70$, $P < 0.0001$).

No attempt was made to sample fish on the deltas. However, the density of 'bullies' (probably *Gobiomorphus cotidianus*) in shallows on the Tekapo/Ohau Delta appeared to be much higher when the lake was lower than normal.

Foraging behaviour

Black stilts appeared to forage exclusively on invertebrates on the Ahuriri Delta. On the Tekapo/Ohau Delta, however, many black stilts were observed foraging on fish as well as invertebrates ('fishing' is defined in Appendix 3). It seems likely that, in the short term at least, the drawdown benefited black stilts by providing an accessible and abundant supply of fish.

Mean pecking rates (excluding rates while fishing) were higher on the Ahuriri and Tekapo/Ohau Deltas (Fig. 5.4) than on other lake deltas and wetlands (Adams 1995; Chapters 3, this thesis). Mean pecking rates (± SE if more than one bird) ranged from 19.5 ± 2.5 to 71 pecks per minute on the Ahuriri Delta and 15 ± 10 to 45 ± 6.8 pecks per minute on the Tekapo/Ohau Delta (Fig. 5.4). Pecking rates did not appear to be related to lake level, but note that sample sizes were small (n = 5 for both deltas). Conversely, stepping rates (not presented) were relatively low on both deltas, and were unrelated to lake level. The moderate to high biomass of food, and pecking rates, and the low stepping rates, support the contention that these deltas provide good foraging habitat for black stilts.

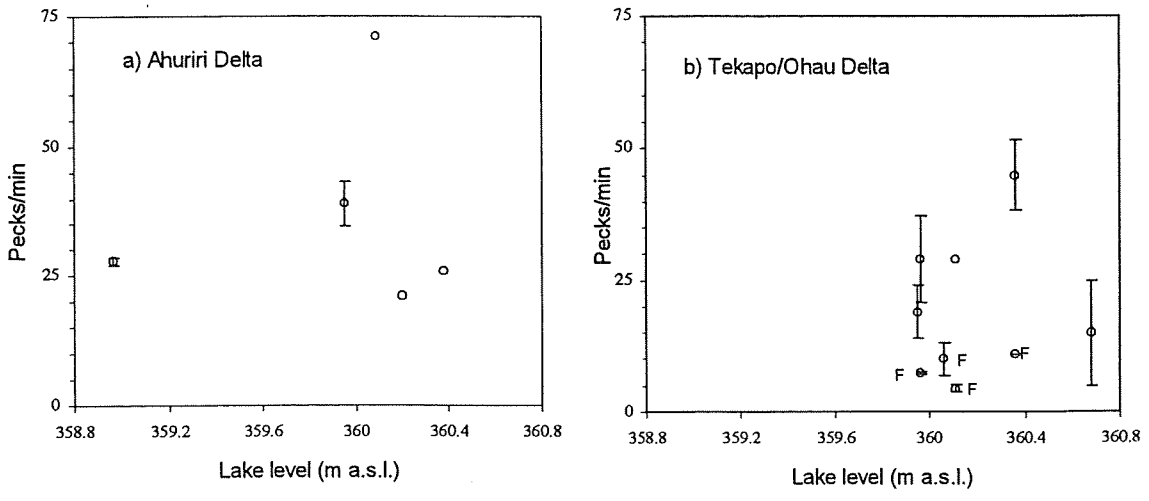


Figure 5.4. Feeding rates of black stilts on the Ahuriri and Tekapo/Ohau Deltas of Lake Benmore during a drawdown in February - March 1994. Each point is the mean feeding rate of all black stilts observed on any one day (*n* ranged from 1 to 10). Bars represent one standard error (where $n > 1$). Mean feeding rates of black stilts that were foraging on fish, or on fish and invertebrates, were calculated separately from those of black stilts foraging on invertebrates only, and are indicated by 'F'.

Physical Habitat

When Lake Benmore is 'full' (*c.* 361.20 m a.s.l.), very little habitat is available to black stilts on the Ahuriri Delta because the water edge is overhung in many places by willows (but see below), *Carex* spp. and long grass (Fig. 2.18). As the lake drops, the amount of open space initially increases slowly because of the relatively steep gradient of the upper shore. However, as the gradient of the shore decreases, the distance to the vegetated shore increases more quickly (*e.g.* Figs. 2.19 & 2.20). Below 361 m a.s.l., mud and sand flats begin to be exposed, particularly in the middle of the delta. The arrival of black stilts on the Ahuriri Delta when the lake fell below 361 m a.s.l. in March 1994 (Fig. 5.2) suggests that a margin of exposed mud as narrow as *c.* 15 m can be sufficient to attract black stilts to the delta.

Below 360.4 m a.s.l. a flat expanse of sand and silt that extended more than four hundred metres into the lake was exposed at the Ahuriri River mouth (Fig. 2.17). Black stilts were almost always sighted foraging in this area during the 1994 drawdown. Although water of foraging depth (< 18 cm) extended an average of 10 - 15 m from the shore at low lake levels (Fig. 5.5c), black stilts appeared to spend most of their time foraging in water < 5 cm deep, or on the wet substratum.

During the 1994 drawdown, willows were removed from the lower Ahuriri River and from the delta. Although tall grasses have replaced the willows near the delta, the increased openness of the habitat may encourage black stilts to use the Ahuriri Delta more readily in future. If so, even small drawdowns may be sufficient to encourage black stilts to use it.

In contrast to the shore of the Ahuriri Delta, the shore at normal water levels on Tekapo/Ohau Delta is much less vegetated (since willows were removed in 1992 and 1993), and usually provides a relatively large area of open habitat (Fig. 2.21). Its gradient is lower than that of the Ahuriri Delta and this is reflected in less extensive shallows and a relatively slow increase in the amount of open space as the lake is lowered (Fig. 5.5b & d).

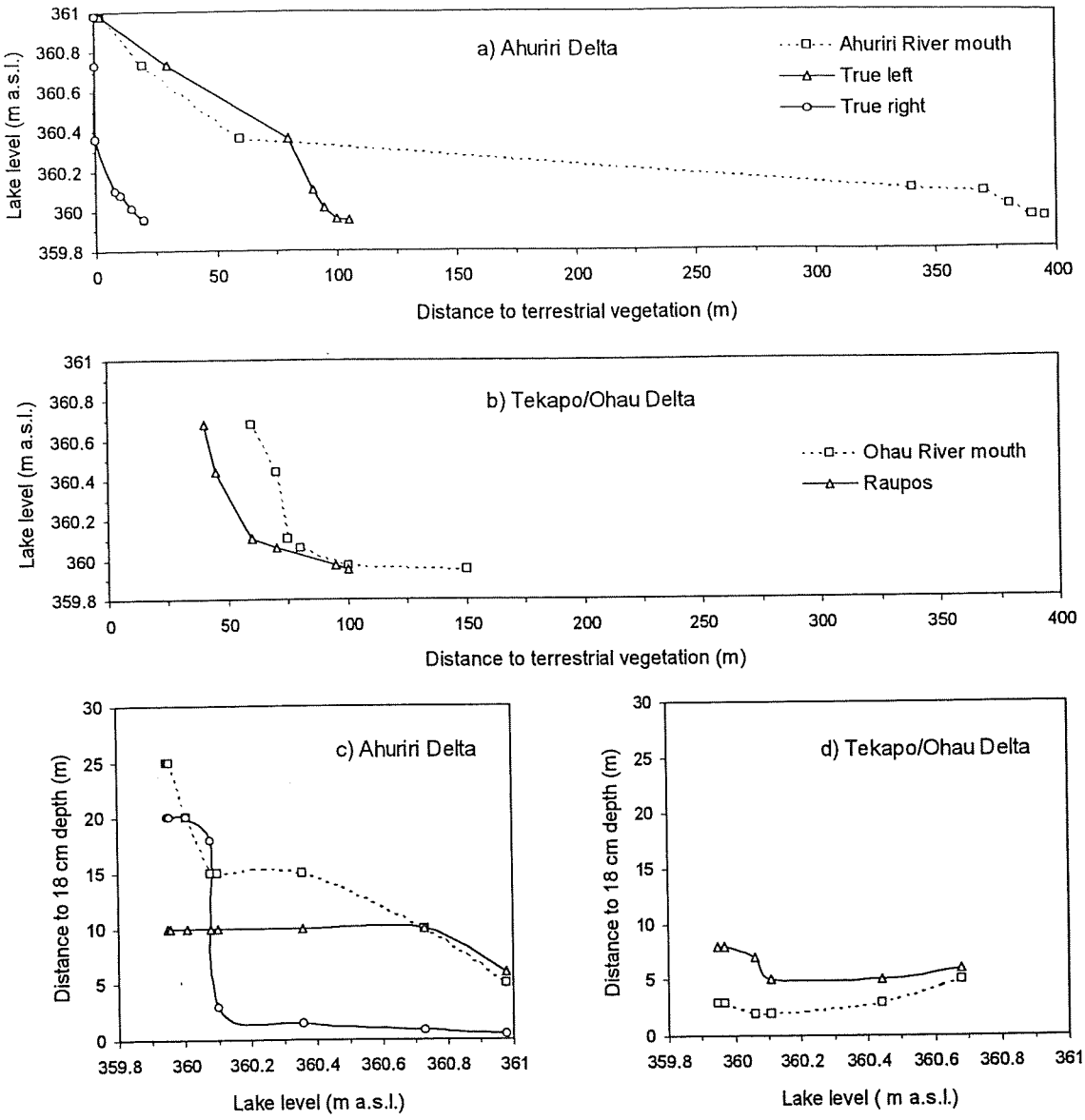


Figure 5.5. Black stilt habitat in relation to lake level as estimated along three transects on the Ahuriri Delta and two transects on the Tekapo/Ohau Delta of Lake Benmore. Plots a) and b) show shore profiles, in terms of distance from the water edge to terrestrial vegetation (note that the vertical scales are greatly exaggerated). Plots c) and d) show how far water of black stilt foraging depth (< 18 cm) extends from the lake edge, at different lake levels. Legends in plots a) and b) also apply to plots c) and d), respectively.

MANAGEMENT IMPLICATIONS

This study provides further evidence that black stilts move on to the Ahuriri and Tekapo/Ohau Deltas in response to drawdowns of Lake Benmore. If this response is fairly consistent, as seems likely, then intentional drawdowns could potentially benefit black stilts in at least four ways:

1. If black stilts congregate on exposed deltas during drawdowns, the opportunity for unpaired black stilts to find mates may be increased. Late winter drawdowns (*c.* August) would be most likely to benefit black stilts in this way, because that is probably when most new pairs are formed (Pierce 1982a).

2. Drawdowns in late winter would also provide abundant pre-breeding season food supplies on both deltas (particularly the Ahuriri Delta). Abundant food supplies should ensure that adults are in good breeding condition, and may increase the probability that pairs will nest.

3. Drawdowns could be used to provide alternative habitat for black stilts if other habitats were unavailable (*e.g.* if ponds and tarns were frozen, or if rivers were dry).

4. Appropriately timed drawdowns may increase the chances that newly released captive-reared black stilts will survive. Between 1993 and 1995, a high percentage of recently released captive-reared black stilts appear to have died because they flew into power lines, fences or aviaries near the release site (perhaps up to 40 %; Adams 1995; Adams pers. comm.). One alternative release site would be the Tekapo/Ohau Delta. Even a small drawdown (*c.* 20 cm) at the time of release may increase the probability that released black stilts will survive, by providing an abundant and accessible food supply, and, perhaps, by encouraging the released birds to stay on the relatively safe open delta.

It is worth emphasizing that these benefits are currently speculative. Nevertheless, given the endangered status of black stilts, the potential of drawdowns as a management technique should be further investigated. In particular, drawdowns in conjunction with releases of aviary birds seem

promising. An evaluation of the potential of drawdowns as a management tool should consider the following questions.

1. Do drawdowns actually benefit black stilts?

2. If so, how much would Lake Benmore need to be lowered to realize these benefits? This question is particularly pertinent because other water users (*e.g.* ECNZ) may prefer to keep Lake Benmore as full as possible. The present study suggests that even a 20 cm drawdown may be useful.

3. How do black stilts respond to drawdowns of different durations and at different times of year?

4. What are the other costs and benefits associated with drawdowns? In particular, studies in New Zealand (*e.g.* Winter 1964; Mark 1987; Mark and Kirk 1987; Stark 1990; but *c.f.* James *et al.* 1995) and overseas (Moon 1935; Hynes 1961; McLachlan 1970; Hunt and Jones 1972; Lyon *et al.* 1986) have shown that increases in water level fluctuations can alter the littoral fauna and flora of lakes, and the physical structure of the shore. Would changes in the water level regime of Lake Benmore adversely affect the flora, fauna, and physical structure of the drawdown zone?

PART TWO

Habitat enhancement

CHAPTER 6

Food supplies at black stilt nest sites

INTRODUCTION

The aim of the experiments described in Chapters 7 - 10 is to develop practical wetland management techniques that can be used to provide an abundant supply of food for black stilts, particularly during the nesting season. Underlying this aim is an assumption that black stilt nest site selection is influenced by the type and amount of food available. Although this assumption has not been formally tested for black stilts, it is supported by my observations of pied stilts (Chapter 11). It is also supported by Pierce (1982a), who observed that black stilts nested in the Cass Valley only where food was plentiful, and suggested a possible minimum theshold for nesting of 1.0 $g.m^{-2}$ invertebrate dry mass. Many studies of other birds have shown a positive relationship between invertebrate food supplies and the number of birds nesting, or their breeding success (*e.g.* Danell and Sjöberg 1977, 1982; Street 1977; Murkin *et al.* 1982, Gardarrsson and Einarson 1994; for reviews see Chapter 9 in Hale 1980; Puttick 1984; Goss-Custard 1984, and Cody 1985).

The chances that black stilts will nest and successfully rear chicks in modified, predator-free wetlands, is likely to be increased if such wetlands provide more 'attractive' food supplies than other, predator infested wetlands. However, it is difficult to evaluate the attractiveness of food supplies to black stilts, for two reasons. First, the influence of the quantity and taxonomic composition of aquatic invertebrates on black stilt habitat selection is poorly understood (but see Chapter 11). Second, apart from very general studies by Budgeon (1977), Dunbar (1978), Merton (1977) and Pierce (1982a, 1982b, 1983), little is known about the type and amount of food supplies at black stilt nest sites. The objective of this study was to measure the quantity and composition of food supplies at black stilt nest sites.

METHODS

Black stilts usually nest between September and late December (Pierce 1983, 1986a), at a variety of lotic and lentic aquatic habitats throughout the Mackenzie Basin. Nests are monitored at

irregular intervals by Department of Conservation staff using a telescope, and most nest sites are visited once or twice to place dummy eggs, or to band chicks. These visits provided opportunities to sample aquatic habitats near nests with minimal extra disturbance to the birds.

Aquatic invertebrates were sampled at one nest in the 1992/1993 and eight nests in the 1993/1994 season, between 28 September and 8 December (Table 6.1). Six of the nests were adjacent to rivers or streams, two were adjacent to semi-permanently flooded pasture, and one was on a clump of vegetation in a muddy swamp. Five samples were taken at each nest site by placing a 0.1 m^2 stainless steel cylinder in the substrate, and disturbing the substrate and sieving the water within the cylinder (see Appendix 4 for details of the sampling method). Samples were preserved in 15 % formalin and transported back to the laboratory where invertebrates were sorted, identified, counted, dried at 60° C, and weighed. Invertebrates in each sample were separated into 'hard-shelled' invertebrates (snails and cased caddisflies), and 'soft-bodied' invertebrates (aquatic insects and Oligochaeta; note that invertebrate biomass is apportioned differently in Chapters 8 and 9). The dry mass of hard-shelled invertebrates was corrected for shell and case mass, as described in Chapter 8.

Table 6.1 Nest sites at which aquatic invertebrates were surveyed. The pair number refers to Department of Conservation identification records.

Nest site	Date sampled	Pair no.	Brief description of aquatic habitat
Lower Ohau	28/9/93	93/3	Stable river, channel *c.* 10 m wide, mainly cobbles
Lower Ahuriri 1	29/9/93	93/5A	River channel *c.* 10 m wide, cobbles & gravel
Lower Ahuriri 2	29/9/93	93/1	River channel *c.* 10 m wide, cobbles & gravel
East Ahuriri 92	8/12/92	92/5	Stable side stream on terrace, 1-3 m wide.
East Ahuriri 93	10/11/93	93/11A	River *c.* 10 m wide, cobbles & gravel
Glentanner Stream	12/11/93	93/12	Small stream, gravels and small cobbles
Coal Creek	11/11/93	93/9	Muddy swamp, some flowing water
Glencairn Irrigation 1	28/9/93	93/2A	Muddy pools and stream in flooded pasture
Glencairn Irrigation 2	28/9/93	93/4A	Muddy pools and stream in flooded pasture

RESULTS AND DISCUSSION

Invertebrate biomass in all samples taken from nest sites was dominated by soft-bodied invertebrates (Fig. 6.1). Mean total biomass (± SE) ranged from 0.36 (± 0.077) $g.m^{-2}$ at Glencairn Irrigation 2 to 4.60 (± 1.00) $g.m^{-2}$ in the Lower Ohau River; the grand mean of invertebrate biomass in all samples was 1.71 $g.m^{-2}$. The range of mean invertebrate biomass in samples from nest sites was similar to that in samples taken from experimental ponds, which demonstrates that artificial wetlands can provide at least adequate quantities of food for black stilts (see Chapter 8 for a more detailed comparison of nest sites and experimental ponds). At two sites, Glentanner Stream and Glencairn Irrigation 2, mean biomass was significantly less than the 1.0 $g.m^{-2}$ nesting threshold suggested by Pierce ($P < 0.05$, 1-tailed t-test, Bonferroni's correction for multiple (9) tests applied). On the other hand, biomass at the other seven sites was close to, or greater than, 1.0 $g.m^{-2}$, and this is probably a useful minimum invertebrate standing crop to aim for when creating wetlands for black stilts.

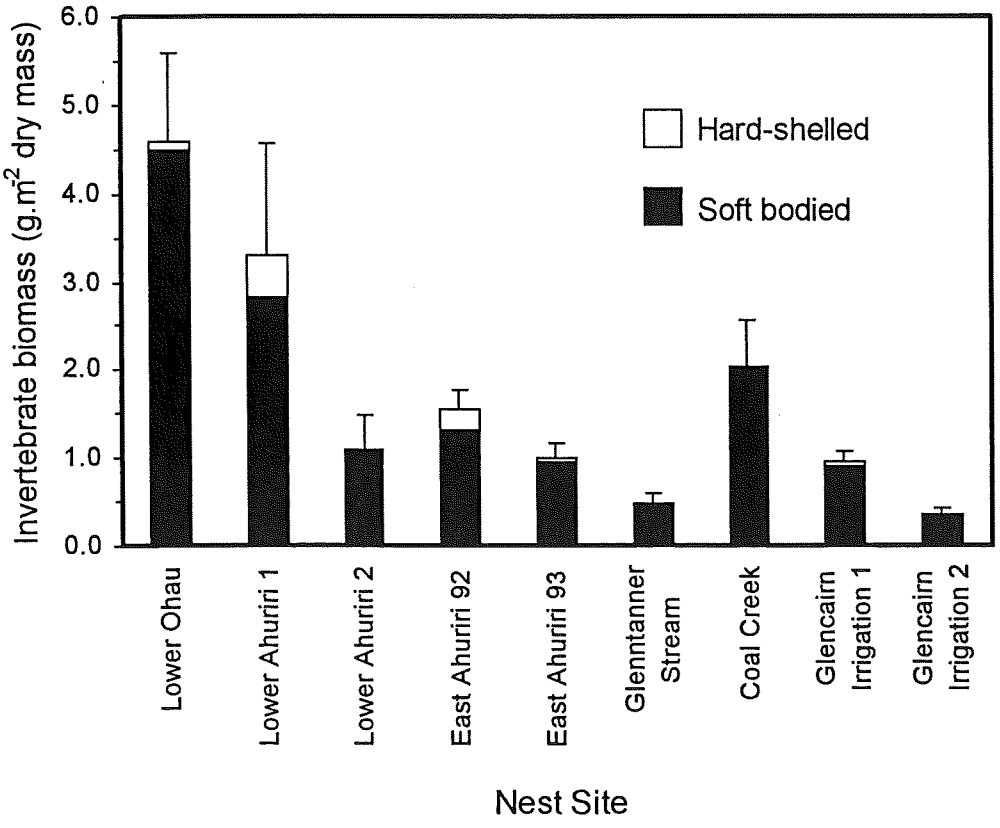


Figure 6.1 Mean biomass (+ 1 SE) of aquatic invertebrates at black stilt nest sites sampled during the 1992/1993 and 1993/1994 nesting seasons.

Numerically, invertebrates in most samples from lotic habitats were dominated by larvae of *Deleatidium* sp. (up to 3240 m^{-2}), or *Deleatidium* sp. and Elmidae (up to 3210 m^{-2}). An exception was Glentanner Stream, where the most abundant taxa were Tanypodinae and Oligochaeta, which were present at maximum densities of 460 m^{-2} and 270 m^{-2}, respectively. Most other taxa occurred in relatively low numbers in most samples, although *Pycnocentrodes* sp. was abundant (> 700 m^{-2}) in samples from Lower Ahuriri River 1, and *Potamopyrgus antipodarum* was abundant (up to 600 m^{-2}) in some samples taken from the East Ahuriri River in 1992.

Samples from lentic habitats were dominated numerically by Oligochaeta, which were present in densities of up to 2550 m^{-2}. Tanypodinae were also abundant (up to 2070 m^{-2}) in samples from Coal Creek. The remainder of the fauna in samples from lentic habitats were present in low numbers (usually < 50 m^{-2}), and consisted mainly of dipteran larvae (*e.g. Chironomus zealandicus*, Stratiomyidae, *Ephydrella* sp. and *Paralimnophila skusei*). Other insect orders, (Coleoptera, Hemiptera, Odonata, Trichoptera) were represented by only a few individuals.

Although abundant in lentic habitats, oligochaete worms may not be a major component of the diet of black stilts, because they burrow out of sight in the sediment. Black stilts feeding in lentic habitats, including the sites surveyed in this study, usually use visual feeding behaviours, rather than tactile ones (Pierce 1982a, 1985, 1986b; pers. obs.). This suggests that they are feeding on invertebrates other than oligochaete worms, a contention that is supported by the very low numbers of oligochaete worms in stomach samples taken from pied and black stilts at lentic habitats where oligochaetes are known to be abundant (Appendices 3 and 7 in Pierce 1982a).

CHAPTER 7

Small-scale substratum addition experiment[1]

INTRODUCTION

The black stilt (*Himantopus novaezelandiae* Gould, 1841) is one of New Zealand's most endangered birds (Williams and Given 1981; Bell 1986; Molloy *et al.* 1994), and is possibly the world's rarest wading bird (Hayman *et al.* 1986). Black stilts were once widespread in the North and South Islands (Pierce 1984a), but are now almost entirely restricted to the Mackenzie Basin, where they inhabit wetlands such as braided riverbeds, lake deltas, ponds, swamps and tarns (Pierce 1982a).

The decline of the species was mostly caused by habitat degradation and the spread of introduced mammalian predators following European colonization of New Zealand (Pierce 1984a, 1986a). In particular, suitable nesting and feeding habitat has been lost mainly as a direct result of hydroelectric and agricultural development. Entire wetlands and braided river systems have been inundated, diverted, drained or channelized. In addition, much of the remaining habitat is of poor quality because of the combined effects of invasive weeds, mammalian predators, continued grazing and falling water tables.

Increasingly, wildlife managers are adopting a habitat-oriented approach in an effort to conserve rare and endangered specialist species, and the protection of remaining fragments of habitat is a key management objective in this approach (*e.g.* Knighton 1985; Kusler and Kentula 1990; Hammer 1992; Helmers 1992). However, some habitats have become so severely degraded that some degree of restoration is required before they become suitable for species or community conservation.

Few attempts have been made to restore wetland habitat for wading birds (see *e.g* Kusler and Kentula 1990; Hammer 1992). Because of the complex and diverse nature of wetlands, and given the overwhelming focus of enhancement programmes towards riparian, fisheries and waterfowl

[1] An earlier version of this chapter was published by Sanders and Maloney (1994). The present version differs slightly from the published paper. Minor formatting changes and typographic corrections have been made and some additional references have been cited. The abstract, acknowledgements and references of the published paper have been incorporated elsewhere in this thesis. The text is essentially unaltered, except that several references to other chapters in this thesis have been inserted within square brackets: [ ].

values, it will be some time before wetland enhancement for waders can be effectively undertaken on a large scale.

In 1990 the Department of Conservation and Electricorp (now ECNZ) signed a compensatory funding agreement called "Project River Recovery" which recognizes the impact of hydro-electric power development on wetland habitats in the Upper Waitaki River catchment (Anon. 1990a). Significantly, the agreement is linked to the rights of ECNZ to use water for power generation (35 year term). It allows for management and enhancement of remaining wetland habitat in reparation for habitat that was lost during the development period (1968 - 1985; Martin 1991).

One of Project River Recovery's aims in the first seven years is to enhance wetlands that will be of particular benefit to the endangered black stilt. Previous attempts at creating wetlands for wading birds in the early 1980s (*e.g.* at Patterson's and Irishman Ponds, adjacent to the Tekapo River) were not successful. These 'old' wetlands are steep-sided, more than 1 m deep and surrounded by tall vegetation, whereas black stilts require shallow water feeding areas, usually surrounded by flat open spaces (Pierce 1982a, 1985, 1986b; Robertson *et al.* 1983). Furthermore, aquatic macroinvertebrates, on which black stilts feed, were present only in very low numbers in samples that I took from several of these old wetlands.

Pierce (1982a) observed that black stilts only reared chicks at sites where aquatic invertebrate biomass was greater than 1 $g.m^{-2}$ dry weight. He also showed that their feeding rate and choice of feeding site were related to prey availability (Pierce 1986b). Therefore, the development of techniques for increasing aquatic macroinvertebrate production and biomass would create the opportunity to enhance or create wetlands as effective black stilt feeding and breeding habitat.

Creation of the open spaces and shallow, predator-free ponds that are suitable for black stilts would be straightforward. However, it is less clear how to produce and maintain adequate food supplies for black stilts. The sites where I found few aquatic invertebrates had compact cobble substrata, covered by silt. Silted substrata provide poor invertebrate habitat (see Ryan 1991), and it is likely that invertebrate production and biomass at these sites is limited by its presence. Previous studies have shown a relationship between invertebrate abundance and substratum type and size. For example, Quinn and Hickey (1990) and Jowett *et al.* (1991) showed that *Deleatidium* sp. and *Aoteapsyche* sp. were more abundant on large stones and cobbles than on small gravels in streams, whilst in Britain, food supplies for wetland birds inhabiting old gravel pits were dramatically increased (especially snails) by the addition of barley straw (Street 1983). Thus, the aim of the work reported in this paper was to identify

substrata that increased the biomass of aquatic invertebrate food supplies for black stilts, and that would be practical to use in large scale habitat enhancement.

METHODS

Study sites

We conducted substratum addition experiments in both pond and stream habitats at one site (Aviary Wetland), and in ponds at two other sites (Mick's Lagoon and Mailbox Inlet) (Fig. 7.1). These sites are

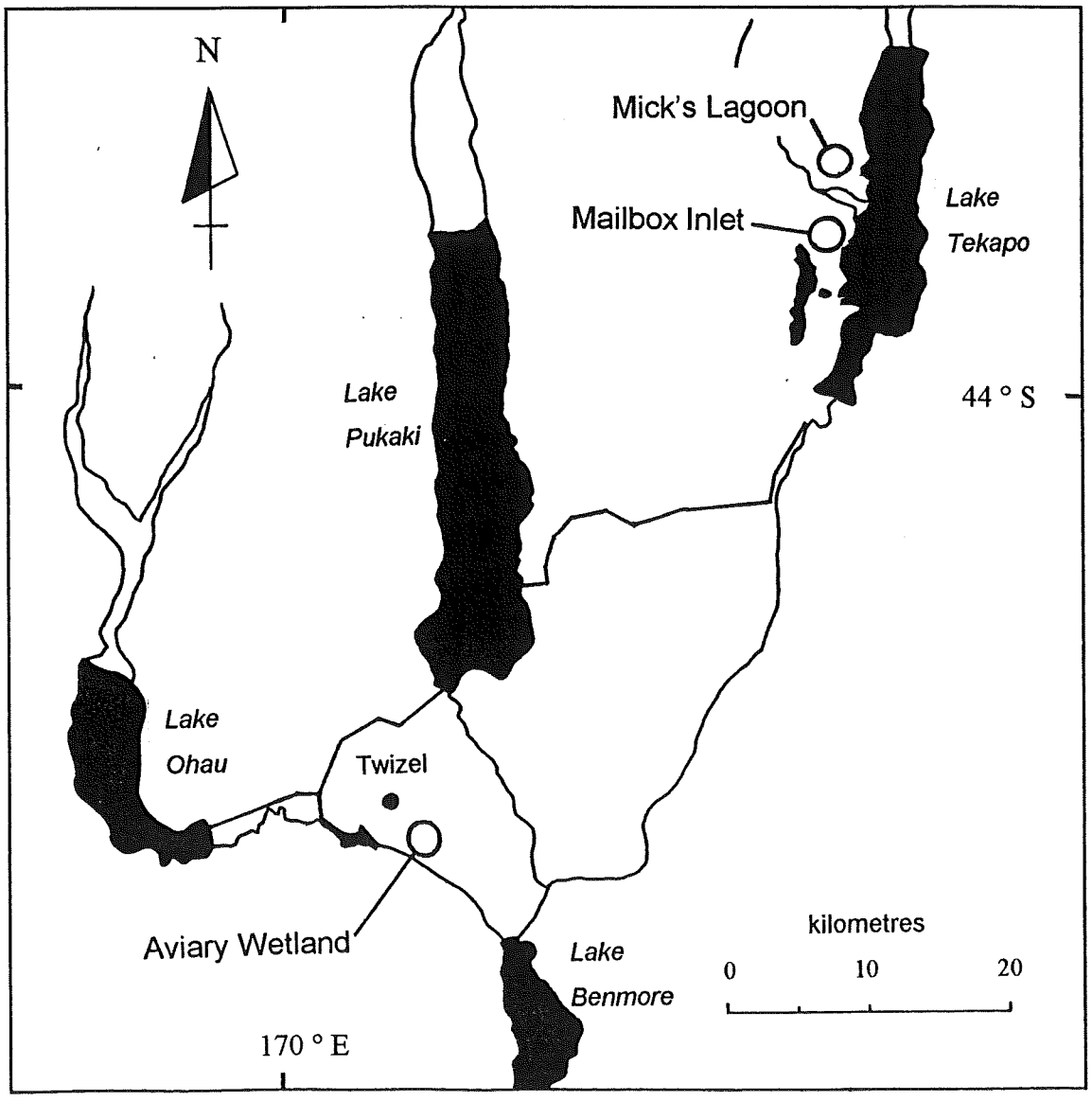


Figure 7.1. Location of study sites in the Mackenzie Basin.

Table 7.1. Ranges of physicochemical factors recorded during the day at the three experimental sites from October to December 1992. Chlorophyll *a* was measured on surfaces of stones, where these were present. N.D. = Not detectable.

Site	Temp. (°C)	Oxygen conc. ($mg.l^{-1}$)	pH	Chloro-phyll *a* ($\mu g.cm^{-2}$)	Conduc-tivity ($\mu S.cm^{-1}$)	NO_3-N ($mg.l^{-1}$)	PO_4-P ($mg.l^{-1}$)
Aviary Wetland ponds	10-29	9.0-12.8	6.4-9.5	0.10-1.5	72	N.D.-0.03	N.D.
Aviary Wetland streams	11-30	10.4-12.5	7.0-9.0	0.15-1.46	73	< 0.03	N.D.
Mick's Lagoon	6-18	9.7-12.6	6.2-10.4	-	108	N.D.	0.04-0.09
Mailbox Inlet	5-21	9.8-17.2	6.4-10.3	-	83	0.08-0.26	N.D.

currently used by black stilts, are enclosed within predator-proof electric fences and are likely to be included in future habitat enhancement programs.

Table 7.1 summarizes physicochemical parameters at the three experimental sites. Temperature ranges were recorded from maximum - minimum thermometers placed under stones at each site for the duration of the experiment. Oxygen concentrations, pH, and conductivities were measured in the early morning and late afternoon at each site on several occasions. Chlorophyll *a* was extracted from stone surfaces using 90% ethanol, and measured spectrophotometrically. Spot water samples were taken within quadrats and in open water, and NO_3-N and PO_4-P concentrations were measured using an auto-analyser (concentrations < 0.03 $mg.l^{-1}$ recorded as trace).

Aviary Wetland is an artificial wetland located on terraces below the Ruataniwha Dam, 3 km from Twizel. Pipes from Lake Ruataniwha supply water to a series of five small ponds (generally < 40 cm deep, 10 - 20 m wide) connected by shallow streams (2 - 15 cm deep, 1 - 3 m wide). The substratum in these streams and ponds consists of fine gravel (< 1 cm diameter) embedded in a hard clay-like pan. A layer of glacial silt covers this pan in the ponds and slower sections of the streams. Water in the streams and ponds was often as warm as 29 - 30 °C by late afternoon during the latter stage of the experiment (October - December).

Table 7.2. Summary of experimental treatments. Substrata that were added to 1 m^2 quadrats (or were present already in the case of controls) are indicated by +.

Site	Control	Topsoil	Large stones	Small stones	Pea straw
Aviary Wetland ponds	+	+	+	+	+
Aviary Wetland streams	+	-	+	+	-
Mick's Lagoon	+	-	-	-	+
Mailbox Inlet	+	-	-	-	+

Juvenile black stilts are reared in three adjacent aviaries before being released to the wild in September. Newly released birds remain near the release point for four to eight weeks following release, and feed at Aviary Wetland and in nearby streams.

Mick's Lagoon and Mailbox Inlet are located on the west side of Lake Tekapo, and are used regularly by black stilts as feeding habitat. Black stilts nested successfully at both sites in the early 1980s (Pierce 1982b). Mick's Lagoon consists of shallow ponds (generally < 40 cm deep) with a soft mud substratum, and is surrounded by *Carex* spp. and pasture. Mailbox Inlet consists of one main pond that has shallow edges and deep (> 1 m) areas. The substratum in the shallows is soft mud or mud and stones. Water chemistry and temperature was similar at both of these sites during October-December 1992. It differed from the Aviary Wetland sites mainly in the lower water temperatures, higher conductivities, and higher NO_3-N and PO_4-P concentrations (Table 7.1). Very high pH (> 10.0) recordings were made on several warm, sunny afternoons.

Experimental Design

Some or all of four types of experimental substrata (pea straw, large stones (screened to 25-60 mm smallest dimension), small stones (screened to < 25 mm smallest dimension) and topsoil) were added to 1 m^2 quadrats at the three sites in September 1992. The type of substratum added to a particular site depended on the suitability of that site, *e.g.* straw and topsoil were not added to streams as they would have been washed away. (Topsoil was added to ponds in Aviary Wetland in a attempt to simulate the apparently highly productive mudflats that occur at many wetlands). Table 7.2 summarizes substratum additions at each site.

Experimental treatments (types of substrata) were replicated five times at each site. At Aviary Wetland, one replicate of each treatment was placed in a quadrat in each of the five ponds and streams. At Mick's Lagoon and Mailbox Inlet five pea straw and five control quadrats were widely interspersed throughout

each site. Black stilts feed in water up to *c.* 18 cm deep (Pierce 1985). Therefore, quadrats were situated in water of about that depth (10-20 cm). Undisturbed natural substrata (described above) were used as controls because these represent the types of feeding habitat currently available to black stilts at each site.

One fifth of a bale of pea straw (approx. 5 kg), or 30 shovelfuls of stones or soil (approx. 5 cm depth) were added to each quadrat. Pea straw was held in place by pegging a galvanised wire netting 'fence' (40 mm mesh, 50 cm high) around the perimeter of quadrats. The mesh size was large enough to allow small fish (*Gobiomorphus* spp.) to enter quadrats. However, large salmonids (if present) and avian invertebrate predators may have been excluded from straw quadrats by the fence.

Sampling methods

All quadrats, except one, were sampled 10 weeks (18 November 1992) and 16 weeks (31 December 1992) after substratum additions. The exception was a quadrat at Mick's Lagoon that had dried up after 16 weeks, and could not be sampled a second time. Invertebrates were collected by holding a triangular net (31 cm sides, 0.8 mm mesh) vertically with its base on the substratum and then rapidly sweeping forward 31 cm, thus sampling 0.1 m^2. Samples were taken near the centre of each 1 m^2 quadrat, to minimize possible edge effects. All substratum within the area sampled was collected in the net during this sweep and, in the case of stone and straw samples, was placed immediately in a large plastic bin. Stones were washed in water in the bin, inspected to ensure they were free of invertebrates, and replaced within the quadrat. The contents of the bin were then poured into the net to drain off the water, transferred to plastic bags and preserved in 70 % ethylene glycol. Straw was placed in the bin without water. Most straw samples were then halved by thoroughly mixing straw in the bin and discarding half the contents. Straw, topsoil and control samples were transferred directly into plastic bags and preserved in 70 % ethylene glycol.

In the laboratory, samples were washed in a 0.8 mm sieve, carefully hand sorted by eye in a white tray, and the detritus was discarded. Invertebrates in each sample were identified (most to family or genus), counted, and dried to constant weight at 60 ± 2 °C. Molluscs, stony-cased caddisflies, and 'soft-bodied invertebrates' from each sample were weighed separately. Body weights of molluscs and stony-cased caddisflies (*i.e.* weights excluding shells and cases, which were assumed to have no nutritional value) were estimated by multiplying total weights by the following conversion factors. Stony-cased caddisflies (*Hudsonema amabilis* and *Pycnocentrodes* sp.), × 0.25; *Potamopyrgus antipodarum* × 0.10; other molluscs (mainly *Lymnaea tomentosa* and *Physa acuta*) × 0.25. Conversion factors were determined by

weighing subsamples of animals, except that the value for *P. antipodarum* was taken from Michaelis (1974).

Statistical analysis

Invertebrate biomass data (body dry weight per 0.1 m^2) from Mick's Lagoon and Mailbox Inlet were analysed together as a three factor, model I ANOVA, with type of substratum, incubation time and location as factors. Aviary Wetland ponds and Aviary Wetland streams were each analysed as two factor, model I ANOVAs, with type of substratum and incubation time as factors. Biomass data were normalized by log transformations, which also reduced variance heterogeneity in Mick's Lagoon and Mailbox Inlet data to non-significant levels (Bartlett's test $P > 0.05$). Variances of both untransformed and transformed Aviary Wetland data were homogeneous (Barlett's test, $P > 0.05$). Tukey's T tests were used for multiple comparisons of means following significant ANOVAs. Invertebrate densities were not compared statistically. For clarity of presentation, untransformed biomass data (including standard error bars) are presented in all figures, although statistical analyses were carried out on log transformed data.

RESULTS

Aviary Wetland ponds

Type of substratum had a significant effect on invertebrate biomass in Aviary Wetland ponds ($F_{[4,40]} = 30.43$, $P < 0.001$), but incubation time did not ($F_{[1,40]} = 0.01$, $P > 0.05$). However, the effect of substratum was influenced by incubation time (*i.e.* significant interaction in the ANOVA, $F_{[4,40]} = 4.71$, $P < 0.005$). Therefore, comparisons of mean biomass among substrata were carried out separately for samples taken at 10 weeks and 16 weeks (Table 7.3). Significant differences are described below. Fig. 7.2a shows mean biomass in Aviary Wetland ponds at 10 and 16 weeks.

Mean (± 1 SE) biomass of invertebrates in pea straw (2.6 ± 0.5 $g.m^{-2}$ dry wt.) was significantly higher 10 weeks after addition to ponds than that in control (0.8 ± 0.3 $g.m^{-2}$ dry wt.) and topsoil (0.5 ± 0.1 $g.m^{-2}$ dry wt.) quadrats. After 16 weeks, mean invertebrate biomass in pea straw had increased dramatically, to 9.1 ± 1.0 $g.m^{-2}$ dry wt., and was significantly greater than the biomass on all other substrata. The latter showed little change between 10 and 16 weeks. Mean biomass was similar on both sizes of stones at both times (1.1 ± 0.3 to 1.47 ± 0.2 $g.m^{-2}$ dry wt.). Invertebrate biomass was always greater than

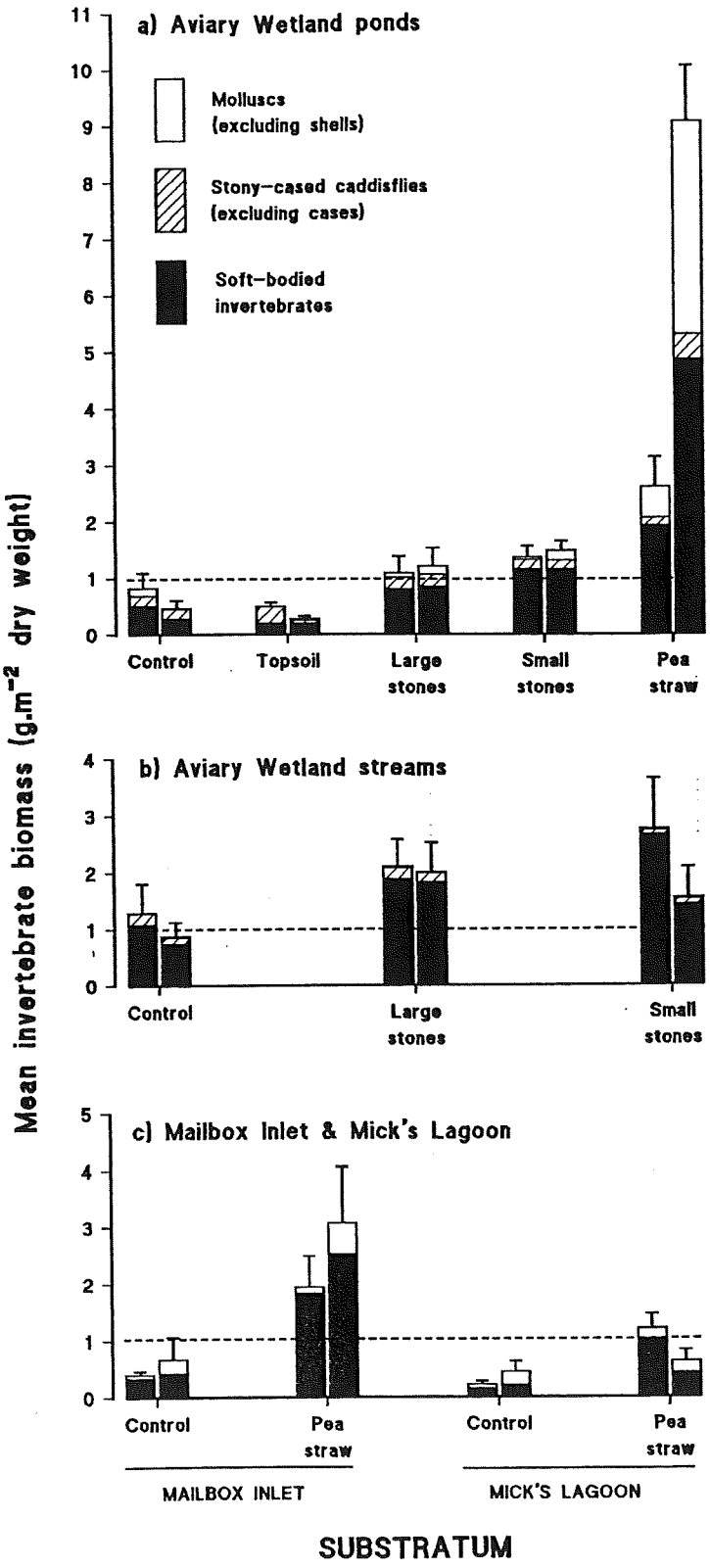


Figure 7.2. Invertebrate biomass (mean ± SE) on four experimental substrata at three sites after 10 weeks (left hand bar of each pair) (n = 5), and 16 weeks (right hand bar) (n = 4 or 5). The horizontal dotted lines indicate a possible threshold below which black stilts might not rear chicks (Pierce 1982a).

Table 7.3. Multiple comparison (Tukey's T test, 5% level of significance) of mean $\log_{10}$ invertebrate biomass on experimental substrata, following a significant ANOVA of Aviary Wetland pond data. Substrata for which means did not differ significantly are denoted by the same letter. Means are compared separately for samples taken at 10 and 16 weeks, because the interaction between time and substratum was significant.

Substratum	10 weeks			16 weeks			
Pea straw	A			A			
Small stones	A	B			B		
Large stones	A	B			B	C	
Control		B				C	D
Topsoil		B					D

1.0 g.m^{-2} dry wt. (putative chick rearing threshold; Pierce 1982a) in stones and pea straw in Aviary Wetland ponds, whereas in topsoil and control quadrats it was always below this level.Mean densities of invertebrate taxa that were greater than 100 m^{-2} at least once are summarized for all sites in Table 7.4. Larvae of *Xanthocnemis zealandica*, which are typically found in drowned grasses or floating weeds (Rowe 1987), were particularly abundant (mean ± 1 SE: 464 ± 127 m^{-2}) in pea straw in Aviary Wetland ponds, as were *Physa acuta* (1896 ± 313 m^{-2}) and *Sigara* sp. (816 ± 295 m^{-2}). *Deleatidium* sp. was abundant on large and small stones in Aviary Wetland ponds, whereas *Hudsonema amabilis* was most abundant in control, topsoil and pea straw quadrats. Oligochaeta were present in pea straw (112 ± 75 m^{-2}) but were absent from other substrata in Aviary Wetland ponds.

Aviary Wetland streams

Type of substratum had a significant effect on invertebrate biomass in Aviary Wetland streams ($F_{[2,24]} = 3.70$, $P < 0.05$). Incubation time did not affect invertebrate biomass at these sites ($F_{[1,24]} = 1.48$, $P > 0.05$), nor did it interact with the effect of substratum ($F_{[2,24]} = 0.27$, $P > 0.05$). Mean biomass was greater on large and small stones than in control quadrats (Fig. 7.2b), although these differences were not significant in multiple comparisons of means (Tukey's T test, $P > 0.05$). Mean invertebrate biomass on large and small stones ranged from 1.5 ± 0.5 to 2.8 ± 0.9 g.m^{-2} dry wt., and was therefore greater than the possible chick rearing threshold. In contrast, mean biomass in control quadrats was closer to 1.0 g.m^{-2} dry wt. Mean biomass in control and stone-filled quadrats was about 0.5 g.m^{-2} dry wt. greater in streams than ponds at Aviary Wetland.

Table 7.4. Mean (SE shown in parentheses) number of invertebrates per m^2 in samples taken from experimental substrata 16 weeks after substratum additions. Only those taxa found at least once at mean densities greater than 100 m^{-2} are shown. C = control, T = topsoil, LS = large stones, SS = small stones, PS = pea straw.

	Aviary Wetland ponds (n = 5)					Aviary Wetland streams (n = 5)			Mick's Lagoon (n = 4)		Mailbox Inlet (n = 5)	
Taxa	C	T	LS	SS	PS	C	LS	SS	C	PS	C	PS
Deleatidium sp.	6 (6)	0 (0)	116 (82)	554 (534)	8 (8)	212 (110)	1116 (378)	898 (369)	0 (0)	0 (0)	0 (0)	0 (0)
Aoteapsyche sp.	0 (0)	0 (0)	4 (2.4)	4 (2.4)	0 (0)	236 (122)	550 (311)	846 (648)	0 (0)	0 (0)	0 (0)	0 (0)
Hudsonema amabilis	446 (90)	318 (137)	82 (40)	24 (24)	264 (62)	56 (22)	102 (29)	40 (11)	0 (0)	0 (0)	0 (0)	0 (0)
Sigara sp.	254 (17)	86 (52)	104 (47)	84 (30)	816 (295)	52 (52)	0 (0)	0 (0)	85 (39)	23 (19)	430 (191)	186 (33)
Berosus sp.	18 (14)	6 (4)	60 (21)	104 (41)	48 (20)	8 (5)	0 (0)	4 (2.4)	5 (2.9)	3 (3)	0 (0)	0 (0)
Xanthocnemis zealandica	4 (4)	4 (4)	14 (9)	58 (23)	464 (127)	0 (0)	8 (8)	0 (0)	5 (5)	13 (13)	4 (2.4)	48 (33)
Lymnaea tomentosa	44 (25)	8 (6)	14 (7)	58 (22)	296 (205)	10 (6)	4 (2)	6 (4)	43 (11)	15 (12)	4 (2)	0 (0)
Gyraulus corinna	0 (0)	2 (2)	4 (4)	2 (2)	80 (44)	0 (0)	0 (0)	2 (2)	0 (0)	3 (3)	94 (60)	124 (72)
Physa acuta	16 (10)	6 (2)	26 (8)	30 (11)	1896 (313)	8 (4)	8 (6)	2 (2)	267 (162)	70 (51)	214 (136)	3200 (2263)
Sphaerium novaezelandiae	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	105 (52)	90 (50)	16 (16)	20 (13)
Chironomidae	42 (31)	18 (16)	38 (11)	36 (29)	152 (61)	32 (17)	32 (15)	30 (13)	0 (0)	0 (0)	4 (4)	0 (0)
Oligochaeta	0 (0)	0 (0)	0 (0)	0 (0)	112 (75)	0 (0)	2 (2)	0 (0)	0 (0)	1500 (1500)	0 (0)	3510 (2300)

Aviary Wetland streams were dominated numerically by *Deleatidium* sp., *Aoteapsyche* sp., *H. amabilis* and Chironomidae, in that order (Table 7.4). Densities of *Deleatidium* sp. and *Aoteapsyche* sp. were highly variable but, on average, were higher on stones than in control quadrats. *H. amabilis* was present at similar densities on small stones (40 ± 11 m^{-2}) and in control quadrats (56 ± 22 m^{-2}), but was twice as abundant on large stones (102 ± 29 m^{-2}). *Sigara* sp. was absent from stones, and other taxa occurred only in low numbers.

Mick's Lagoon and Mailbox Inlet

Type of substratum ($F_{[1,30]} = 25.67$, $P < 0.001$) and location ($F_{[1,30]} = 9.26$, $P < 0.005$) significantly affected invertebrate biomass at Mick's Lagoon and Mailbox Inlet; mean biomass was greater in pea straw quadrats than control quadrats at both sites, and was greater at Mailbox Inlet than at Mick's Lagoon (Fig. 7.2c). Neither incubation time ($F_{[1,30]} = 0.03$, $P > 0.05$), nor any interaction terms in the ANOVA were significant ($P > 0.05$ for all interaction terms).

The invertebrate faunas at Mick's Lagoon and Mailbox Inlet were dominated numerically by Oligochaeta, *P. acuta*, and *Sigara* sp. (Table 7.4). At Mailbox Inlet, *P. acuta* was much more abundant on pea straw than in control quadrats but at Mick's Lagoon, where numbers were lower, the reverse was found. *Sigara* sp. was more abundant at Mailbox Inlet than Mick's Lagoon, and was about twice as abundant in pea straw as in control quadrats at both sites. At both sites, as in Aviary Wetland, *X. zealandica* was more abundant on pea straw than in control quadrats. However, *X. zealandica* was much less abundant at these sites than in Aviary Wetland ponds. Oligochaeta were abundant in pea straw and absent from control quadrats at both sites.

DISCUSSION

I investigated the effect of substratum additions on aquatic invertebrate biomass and taxonomic composition, in three wetlands. This initial, small-scale research was motivated by a need to develop practical techniques for the enhancement of food supplies for black stilts in future, large-scale wetland enhancement projects.

I found that mean invertebrate biomass in samples taken from quadrats to which pea straw had been added was always greater than that in other substrata. The difference was most dramatic 16 weeks after substratum additions to Aviary Wetland ponds. At that time mean biomass in pea straw was over 18 times that in control and topsoil quadrats, and *c.* 6 times that in quadrats containing large or small stones. High invertebrate biomass in pea straw was brought about mainly by high densities of *Xanthocnemis zealandica* larvae and, to a lesser extent, *Physa acuta* (except at Mailbox Inlet) and Oligochaeta.

Results of these initial substratum experiments using pea straw are very encouraging. I have been able to produce high invertebrate biomass, including an abundance of *X. zealandica*; a large, slow moving, easily visible species that is likely to provide an accessible food source for black stilts.

Samples from large and small stones had consistently higher mean biomass than samples from controls. Although these differences were usually not statistically significant, the addition of stones to wetlands to increase black stilt food supplies seems worth further investigation [see Chapter 8]. *Deleatidium* sp. and *Aoteapsyche* sp. were generally more abundant on stones than on other substrata, whereas *Hudsonema amabilis* and *Sigara* sp. were most abundant in control quadrats in ponds. All these species are known to be taken by black stilts (Budgeon 1977, Pierce 1982a, 1985, 1986b), but whether they differ in their value as food is unknown [see Chapter 10].

Topsoil was added to ponds in Aviary Wetland in a attempt to simulate the highly productive mudflats that occur at many wetlands. However, rather than being very productive, topsoil areas had the lowest densities and biomass of all experimental quadrats, including controls, and will not be investigated further.

Several questions need to be addressed before substratum addition is considered as a technique for the enhancement of food supplies in large wetlands (*i.e.* several hectares in area). Firstly, will this technique work at a large scale? Lining an entire wetland with straw, for example, will almost certainly affect water chemistry and temperature (and therefore potentially affect invertebrates) more strongly than 1 m^2 quadrats of straw. Furthermore, invertebrate community composition and abundance in small patches of habitat (as in the present study) may well differ from those in an entire wetland of the same habitat type.

Secondly, what long-term effects will substratum additions have? Interstices between stones may become filled with silt and the straw will decompose. Large-scale (5-10 m diameter), long-term experiments are currently under way in the Mackenzie Basin [see Chapters 8 and 9] to test the feasibility of substratum additions as a management technique.

Finally, will black stilts feed in wetlands to which substrata have been added? [They do - see Chapter 11.] Our study did not examine whether the invertebrates on particular substrata are actually *available* as food for black stilts, nor whether certain food types are *preferred*. Black stilt adults have been described as generalist, opportunistic feeders, that take whatever invertebrates are available (Budgeon 1977, Pierce 1982a, 1985). Nevertheless, observations of captive adults and chicks suggest that some prey may be preferred (*e.g.* larval Hydrobiosidae, Hydropsychidae and *Deleatidium* sp.),

whereas others are avoided (*e.g.* large *Lymnaea stagnalis*), or are less available (*e.g.* newly hatched chicks have difficulty in eating *Hudsonema amabilis* [Chapter 10]). If wetland enhancement aims to provide successful breeding areas, suitable food supplies for chicks must be identified and enhanced. Therefore, food preferences of black stilts, focusing on food selectivity of chicks, should be investigated [see Chapter 10].

CHAPTER 8

Large-scale substratum manipulation experiment

INTRODUCTION

Over the past 15-20 years there has been a dramatic increase in the number of wetland creation and enhancement projects being undertaken to provide habitat for wetland birds (Scott 1982; Knighton 1985; Kusler and Kentula 1990; Schneller-McDonald *et al.* 1990 Hammer 1992; Helmers 1992). The abundance of wetland birds is often correlated with the availability of aquatic invertebrates, on which many wetland birds feed (*e.g.* Murkin *et al.* 1982; Puttick 1984; Goss-Custard 1984; Hockey *et al.* 1992; Phillips 1991; Velasquez 1992; Cullen 1994), and wetland managers frequently aim to increase the value of wetlands to birds by maximising the availability of aquatic invertebrates. Management practices that increase aquatic invertebrate availability are well established and widely used (*e.g.* Andrews and Kinsman 1990; Cross 1990; Helmers 1992). In particular, gradually lowering water levels during spring (when birds are breeding) benefits many wetland birds by exposing invertebrate-rich substrata, and concentrating invertebrates at the water edge (Fredrickson and Reid 1988; Fredrickson 1991; Helmers 1992; Kelley *et al.* 1993). However, although the invertebrates that are already present in wetlands can be made more available to birds, relatively little attention has been directed at increasing invertebrate standing crop, and therefore the amount of food in wetlands that is potentially available to birds (but see Street 1983, Gabor *et al.* 1994, Murkin *et al.* 1994). Nor has much attention focussed on managing invertebrate community composition in wetlands to provide more suitable food supplies for wetland birds.

The composition and standing crop of aquatic invertebrates in wetlands is partly determined by the availability of particulate organic material (POM), which provides invertebrates with habitat and food (Minshall 1984), and several studies have shown that increasing the quantity of POM in wetlands can increase invertebrate standing crop, and alter invertebrate community composition. For example, additions of barley straw to flooded gravel pits in England, resulted in dramatic increases in invertebrate standing crop, and changes in community composition (Street 1983), and additions of organic material to salmonid fisheries in Norway (Raastad *et al.* 1993) resulted in increased invertebrate production. Also, it has been found that recently flooded vegetation often

produces a 'flush' of invertebrates (Reid 1985; Murkin and Kadlec 1986). Therefore, where practical, wetlands can be managed on a rotational basis to ensure that newly flooded vegetation is available to birds, particularly during the breeding season (Fredrickson and Reid 1988; Fredrickson 1991; Helmers 1992; Kelley *et al.* 1993;).

Another factor that influences invertebrate composition and standing crop is the particle size composition of the inorganic substratum (reviewed by Minshall 1984). Although particle size will depend strongly on the substratum at any particular site, it can also be influenced by the methods used to construct wetlands. For example, Giles (1986) reported that substrata in wet-dug gravel pits in England are finer than, and support a different invertebrate community to, dry-dug gravel pits. Moreover, field experiments suggest that the addition of inorganic substrata may be a viable management technique to influence invertebrate composition and standing crop at some sites. For example, Sanders and Maloney (1994) showed that invertebrates were more abundant in patches of stones added to ponds with fine substrata than in control patches of fine substratum. Similarly, Francis and Kane (1995) demonstrated that the species composition and abundance of chironomid larvae in patches of substrata varied with substratum particle size.

Thus, managers can, in theory, influence the quantity of invertebrates and the composition of communities in wetlands by their choices of construction methods, and by additions of organic and inorganic material. However, it is not at all clear which construction methods and substratum additions, if any, will be most suitable for wetland construction or enhancement at any particular site. To plan wetland creation and enhancement projects, managers need to compare the likely effects of various construction methods and substratum additions on the composition, standing crop, and succession of invertebrate communities. However, the ability to make such comparisons is limited, because studies conducted at different sites usually vary in their sampling methods, in the variables used to quantify invertebrate response, and in the season and duration of study.

An opportunity to overcome some of these limitations was provided by a wetland enhancement project (Project River Recovery, or 'PRR') that is being undertaken by the New Zealand Department of Conservation, in the Upper Waitaki Basin, in the central South Island of New Zealand (Fig. 1.2). One of the aims of PRR is to create foraging and nesting habitat for the endangered black stilt (*Himantopus novaezelandiae* Gould, 1841). The abundance of black stilts has declined mainly because of predation by introduced mammals such as ferrets and cats (Pierce 1982a, 1984a, 1986a, 1987), which can be excluded from artificial wetlands by fencing and trapping. To encourage black stilts to forage within artificial, predator-free wetlands, rather than in

other, predator-infested areas, the artificial wetlands need to be attractive to black stilts. Because black stilt habitat selection appears to be influenced by the type and amount of aquatic invertebrates in wetlands (this thesis, Chapters 5 and 11; Pierce 1982a, 1985), PRR managers aim to ensure that wetlands provide large quantities of suitable invertebrate prey. The problem faced by PRR, and presumably wetland managers elsewhere, is: which of several available sites, construction methods, and substratum additions will provide the best food supplies for their target bird species? Furthermore, how quickly, and for how long, will artificial wetlands provide suitable food supplies? The principal aim of my study was to compare, over time, the effects of construction method, substratum additions and site on the quantity and taxonomic composition of aquatic invertebrates in artificial ponds. These factors were investigated by conducting replicated field experiments at six sites in the Upper Waitaki Basin.

To be useful for bird management, data that describe invertebrates must be interpreted in terms of the value of those invertebrates to the target bird species. However, because detailed knowledge of the preferences of birds for particular invertebrate species is almost completely lacking, taxonomic lists defining invertebrate communities are largely redundant. On the other hand, lumping all invertebrates together and considering only their pooled biomass or abundance ignores observational data, which usually provides some indication of the value of broad types of invertebrates to birds. In this study, I interpret invertebrate biomass in terms of four food types: oligochaete worms, chironomid larvae, 'nekton', and hard-shelled invertebrates. These food types are defined in the Methods.

Ideally, managers would like to predict the type and amount of invertebrates that will occur when they construct or modify wetlands at various sites, using various methods. Even a limited ability to make such predictions can help managers choose among alternative sites and methods. The second aim of this study was to develop models that relate site conditions before wetland construction to total invertebrate biomass, and to biomass of the four food types outlined above.

The physical conditions of newly created ponds differed among the sites and substrata investigated in these experiments. However, as ponds aged they appeared to become more physically similar, within and among sites. They also appeared to become more like old wetlands, which were already present at most sites. The final aim of this study was to investigate whether apparent convergence in the physical conditions in ponds was paralleled by a convergence in their invertebrate communities.

METHODS

Pond creation experiments were undertaken between August 1993 and December 1994 at six sites in the Upper Waitaki Basin (Fig. 8.1). These sites will be, or are likely to be, the locations of future large-scale wetland development (PRR plans and work currently under way). They also represent a wide range of the substrata and hydrologic and physico-chemical conditions (Table 8.1) of other potential wetland development sites in the Upper Waitaki Basin. At each site, a replicated field experiment was conducted to compare aquatic invertebrate biomass and community composition in ponds with different substrata (defined below). Only those substrata that were considered to be suitable for future large-scale wetland creation at each site were investigated.

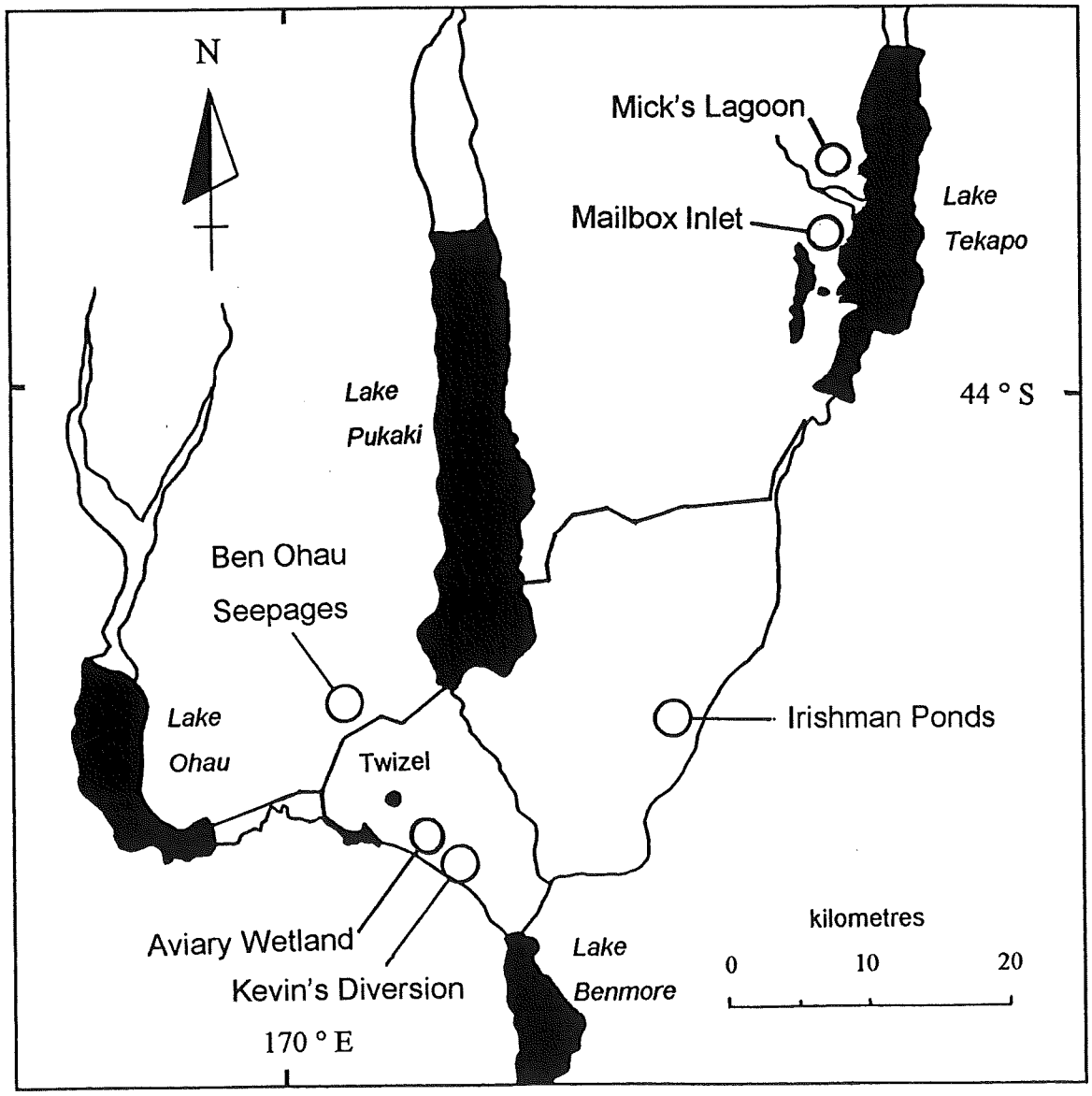


Figure 8.1. Locations of experimental sites in the Upper Waitaki Basin.

Table 8.1. Range of physico-chemical conditions recorded at the six sites on the date or dates when invertebrate samples were taken. The range of temperatures that occurred over the duration of the experiments are also shown. Physico-chemical conditions did not differ among experimental substrata within sites.

Site	Temperature range (° C)		pH	$[O_2]$	Conductivity
	Duration	Spot		$mg.l^{-1}$	($\mu S.cm^{-1}$)
Tekapo Delta	6-26	16-22	5.9-7.8	6.5-11.4	46-111
Aviary Wetland	1-26	17-26	8.0-8.7	9.0-12.0	47-62
Irishman's Ponds	3.5-35	18-22	7.0-8.6	9.5-14.0	45-50
Kevin's Diversion	0-22	15-22	7.6-8.8	9.0-11.8	66-78
Ben Ohau Seepages	2-34	14-30	6.6-8.2	9.0-11.2	18-27
Mick's Lagoon	1-34	18-28	5.9-10.3	6.5-14.5	30-103

Ponds were constructed at the end of winter (late August, 1993) and were sampled 3 and 15 months later, in late November/early December, 1993 and 1994. Sampling dates were chosen to coincide with the middle of the black stilt nesting season (late spring).

Site descriptions

The Upper Waitaki Basin (Fig. 8.1) is a large intermontane basin that lies in the rain shadow to the east of the Southern Alps, and ranges in elevation from *c.* 360 m a.s.l. to *c.* 710 m a.s.l. The floor of the basin consists of glacial till and moraines of varying ages, outwash gravel, and alluvial fans (Fitzharris *et al.* 1992). Runoff from the catchment surrounding the basin flows *via* large braided rivers into three large lakes of glacial origin (Tekapo, Pukaki and Ohau), which in turn are drained by braided rivers. Although rainfall in the basin is low, rivers, lakes, swamps and tarns once provided extensive wetland habitats. In recent times, however, farming, hydroelectric power generation, river control works, and invasion by exotic plants have dramatically reduced and altered the area and nature of wetlands in the Upper Waitaki Basin.

The Tekapo Delta (Fig. 8.2a) is formed by the braided Tekapo River where it enters Lake Benmore. The substratum near the lake edge is a mosaic of stony river channels and muddy areas. Ponds in both muddy and stony areas were constructed by excavation and flooding. Ponds in stony areas that were constructed by excavation were raked with the bucket of the excavator to bring stones to the surface, above the fine material. Ponds in muddy areas were surrounded by grasses and other low vegetation, while those in stony areas had little or no vegetation nearby. Small bays at the lake edge were treated as 'old ponds' at this site.

Aviary Wetland (Fig. 8.2b) was created on an old river terrace in the mid 1980s by piping water from nearby Lake Ruataniwha, to form a series of small ponds connected by shallow streams. These streams were dammed to form 21 ponds for use in this study. The ponds filled very slowly because of water loss through seepage, and were only sampled 15 months after pond construction. Substrata in the old ponds consisted of fine gravel (< 1 cm diameter) embedded in a compacted silt pan and covered with a layer of very fine glacial silt. Substrata in the new ponds consisted initially of a thin layer of soil and sparse terrestrial vegetation (*e.g. Hieracium* spp., *Rumex acetosela*).

Irishman's Ponds (Fig. 8.2c) were constructed on old riverbed adjacent to the Tekapo River in the early 1980s. The newly created ponds used in this experiment were constructed by excavating small ponds adjacent to, and joining the existing (larger) ponds. The substratum in old ponds consisted of cobbles covered in a thick layer of silt, whereas the substratum in newly created ponds consisted mainly of cobbles. Some ponds were excavated and raked, as on the Tekapo Delta, while others were simply excavated. Two zones were recognisable in the old Irishman's Ponds; shallow margins, occupied by emergent plants, particularly *Juncus* spp., and deeper, unvegetated areas. Old pond samples were taken from the shallow margins as I considered this habitat most indicative of potential future wetlands at this site.

Kevin's Diversion (Fig. 8.2d) was the only site that did not have permanent lentic wetlands. Ponds at Kevin's Diversion were constructed on an old river terrace 5 km downstream from, and superficially similar to that at Aviary Wetland. However, the soil at Kevin's Diversion was deeper than that at Aviary Wetland, and the ponds were supplied by abundant, clear spring-fed water, rather than the silt-laden water at Aviary Wetland.

Ponds at **Ben Ohau Seepages** (Fig. 8.2e) were excavated in a shallow boggy area and were also supplied directly with spring water. Small bays in a series of deep ponds constructed in the early 1980s were defined as 'old ponds' at Ben Ohau Seepages.

Mick's Lagoon (Fig. 8.2f) consists of several large, shallow ponds (up to 60 m wide and mainly < 30 cm deep) surrounded by boggy areas and some solid ground. A layer of peaty substratum overlies silty-clay at this site. The vegetation is dominated by sedges (*Carex* spp.) and rushes

(*Juncus* spp.) in the wettest areas, and by grasses and tussocks (*Festuca* sp.) in the driest areas. Stones were not added to Mick's Lagoon, because they would have simply sunk into the deep mud.

Food types

The four food types recognised in this study (Oligochaeta, Chironomidae, hard-shelled invertebrates and nekton) can be recognised in most wetlands, are broadly different ecologically, and appear to differ in their value as food for black stilts.

Oligochaeta burrow out of sight in fine sediments, and are usually small. Although preyed upon by black stilts (Merton 1977; Pierce 1982a), Oligochaeta are probably less valuable as food than other food types, because birds must use tactile rather than visual foraging methods to capture them.

Chironomid larvae are commonly represented in new wetlands by high numbers of one of various collector-browser species (Nursall 1952; Paterson and Fernando 1969; McLachlan 1974; Street and Titmus 1979). In this study the larvae of *Chironomus zealandicus* dominated the chironomid fauna. Although larvae of this species burrow within the sediment, they tend to occur at the substratum surface (*e.g.* Robb 1966) where their red colour makes them highly visible. *C. zealandicus* appears to be a highly attractive prey to black stilts (this thesis, Chapters 5, 10, 11; Pierce 1985). Other studies have reported positive correlations between chironomid density or biomass and numbers of birds using wetlands (*e.g.* Danell and Sjöberg 1977; Phillips 1991; Gardarsson and Einarsson 1994) and it seems likely that chironomid larvae are a highly attractive food to many wetland birds.

Hard-shelled invertebrates consist of molluscs and stony-cased caddisflies, and appear to be the least attractive prey to black stilts. Although molluscs are slow moving and easily captured, they are largely ignored by black stilts in aviaries, despite often being abundant there. Moreover, feeding trials with black stilt chicks (Chapter 10) showed that molluscs and stony-cased caddisflies were consumed only in low numbers, especially by very young chicks. This was partly because they had difficulty handling these prey, but also because chicks would often reject hard-shelled invertebrates that they had captured. Molluscs may be essential as a source of calcium for some birds (Graveland and Van Gijzen 1994, and references therein) but do not appear to be particularly attractive as a food for black stilts.

a) Tekapo Delta

b) Aviary Wetlands

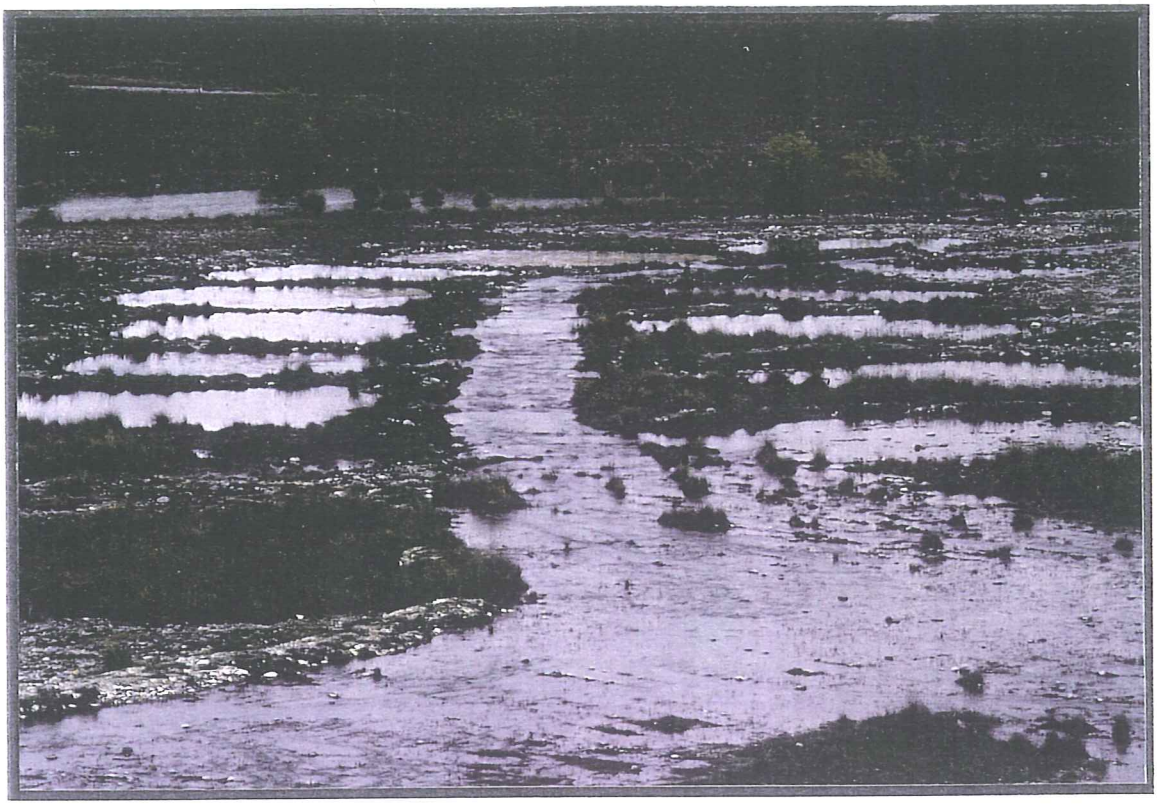
Figure 8.2. Examples of ponds at the six experimental sites.

c) Irishman's Ponds

d) Kevin's Diversion

Figure 8.2. continued

e) Ben Ohau Seepages



f) Mick's Lagoon

Figure 8.2. continued

The final food type recognised in this study, nekton, was defined as all aquatic macro-invertebrates not included in the above three groups. In this study, nekton was dominated by the waterboatman, *Sigara* sp. (Hemiptera: Corixidae), larvae of the damselfly, *Xanthocnemis zealandica* (Zygoptera: Coenagrionidae), and various beetles (Coleoptera: Dytiscidae, Elmidae and Hydrophilidae), but also included other non-chironomid insect larvae (Diptera, Trichoptera and Ephemeroptera), leeches (Hirudinea), mites (Acari) and amphipods (Amphipoda). Most of these taxa are highly visible and mobile, and appear to be very attractive to black stilts (Chapter 10, pers. obs.). In feeding trials (Chapter 10), black stilt chicks clearly fed most vigorously on waterboatmen, which were the fastest moving prey presented.

Substrata

The range of substrata investigated at each site was produced by various combinations of construction methods, substratum additions, and existing substrata (see below, Table 8.2, and Fig. 8.3). Ponds were constructed with a Hitachi EX 200 excavator, equipped with a 2 m wide bucket with *c.* 20 cm long teeth, either by excavation or by building low dams and flooding the ground behind the dams. Excavated ponds were 7 - 15 m in diameter and 10 - 30 cm deep, while the size and depth of flooded ponds depended on the micro-topography of each site. At two predominantly stony sites, Tekapo Delta and Irishman's Ponds, the bucket of the excavator was used to rake the excavated substratum in some ponds back and forward, to bring the coarser material to the top. Thus, three types of pond construction method are defined in these experiments; 'excavated', 'excavated and raked' (Fig. 8.3a) and 'flooded' (Table 8.2).

Two types of substratum addition were investigated; barley straw (Fig. 8.3b) and stones (Fig. 8.3c). Barley straw was added to five ponds at all sites soon after construction, with the exception of Aviary Wetland. At Aviary Wetland, straw was added to ponds 12 months after construction because ponds were not full until then. A thick layer of straw (*c.* 2 $kg.m^{-2}$) was spread over each pond and thoroughly wetted. The straw floated at first but after 10 days had sunk to form a buoyant open matrix from the bottom of the ponds to the water surface. A 10 cm deep layer of large stones (*c.* 5 - 20 cm long) was added to three sites with fine substrata. Ponds to which stones were added were initially constructed deeper so that the final depth of the water was similar to that of other ponds.

At five of the six sites investigated, lentic wetlands already existed. Within each of these extant wetlands five shallow-water sites were also sampled; these are referred to as 'old ponds' (Fig.

Table 8.2. Summary of substratum manipulations investigated at the six experimental sites. Codes for each combination of site and substratum are shown in parentheses; these codes are referred to in Fig. 8.5 and Table 8.6. Each substratum was replicated at each site; n=5, except where indicated in brackets. Similar substrata appear in the same row. Total number of ponds at each site is shown in the bottom row.

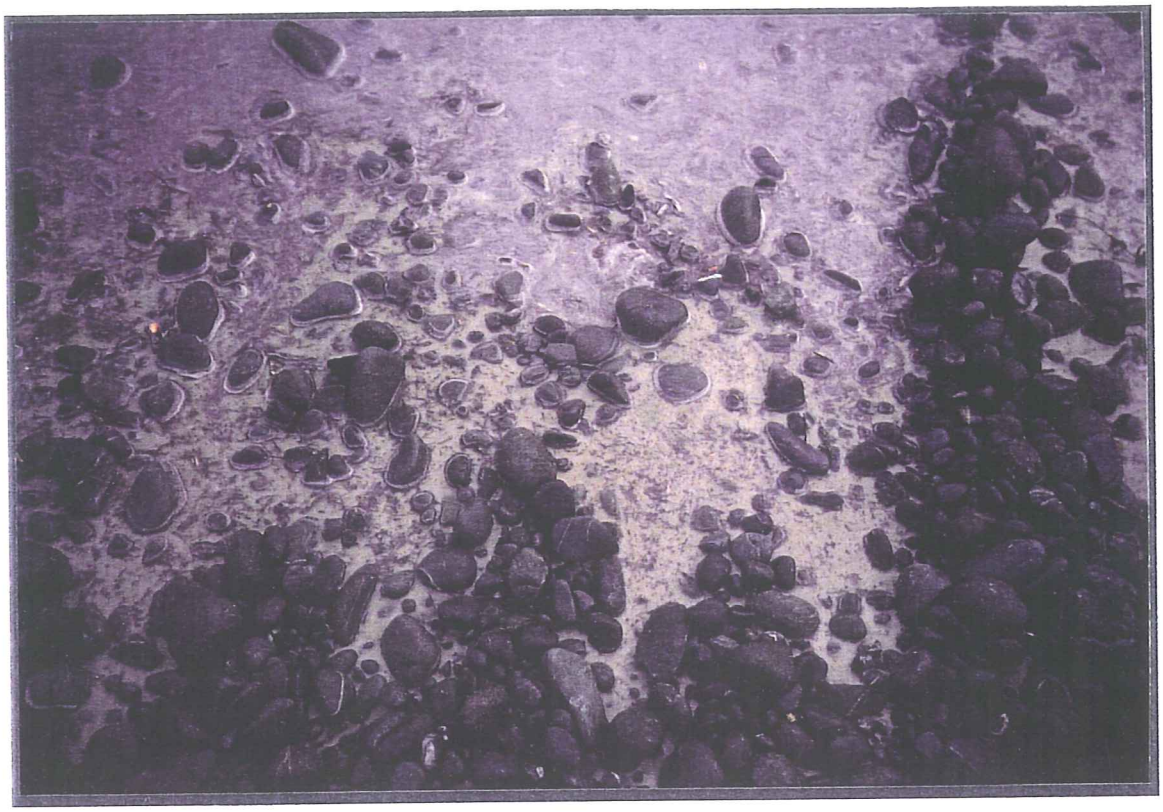
Site	Tekapo Delta	Aviary Wetland	Irishman's Ponds	Kevin's Diversion	Ben Ohau Seepages	Mick's Lagoon
Times sampled	3 months	15 months	3 months	3 months 15 months	3 months 15 months	3 months 15 months
Substratu	Old (TO)	Old (AO)	Old (IO)	-	Old (BO)	Old (MO)
	Excavated & raked stones + barley straw (TRB)	Flooded + barley straw [n=4] (AFB)	Excavated + barley straw (IEB)	Excavated + barley straw (KEB)	Excavated + barley straw (BEB)	Excavated + barley straw [n= 3 or 5] (MEB)
	Excavated mud (TEM)	-	Excavated [n=6] (IE)	Excavated (KE)	Excavated (BE)	Excavated (ME)
	Excavated & raked stones (TR)	Flooded + stones [n=4] (AFS)	Excavated & raked stones [n=4] (IER)	Excavated + stones (KES)	Excavated + stones (BES)	-
	Flooded mud (TFM)	Flooded (AF)	-	Flooded (KF)	-	-
	Flooded stones (TFS)	-	-	-	-	-
Number of ponds	30	18	20	20	20	15

8.3d). At the sixth site, Kevin's Diversion, a narrow stream was present before the ponds were constructed, but was dammed to create the ponds. Thus no 'old' wetland remained to be sampled at Kevin's Diversion.

Sampling

Four 'subsamples' were taken from each pond on each sampling occasion - one from each quarter of each pond. These subsamples were pooled and sub-divided in the field (details below) to yield a single representative sample from each pond. Each subsample was taken by placing a 0.1 m^2 stainless steel cylinder in the pond at *c.* 15 cm depth, (the approximate maximum depth to which

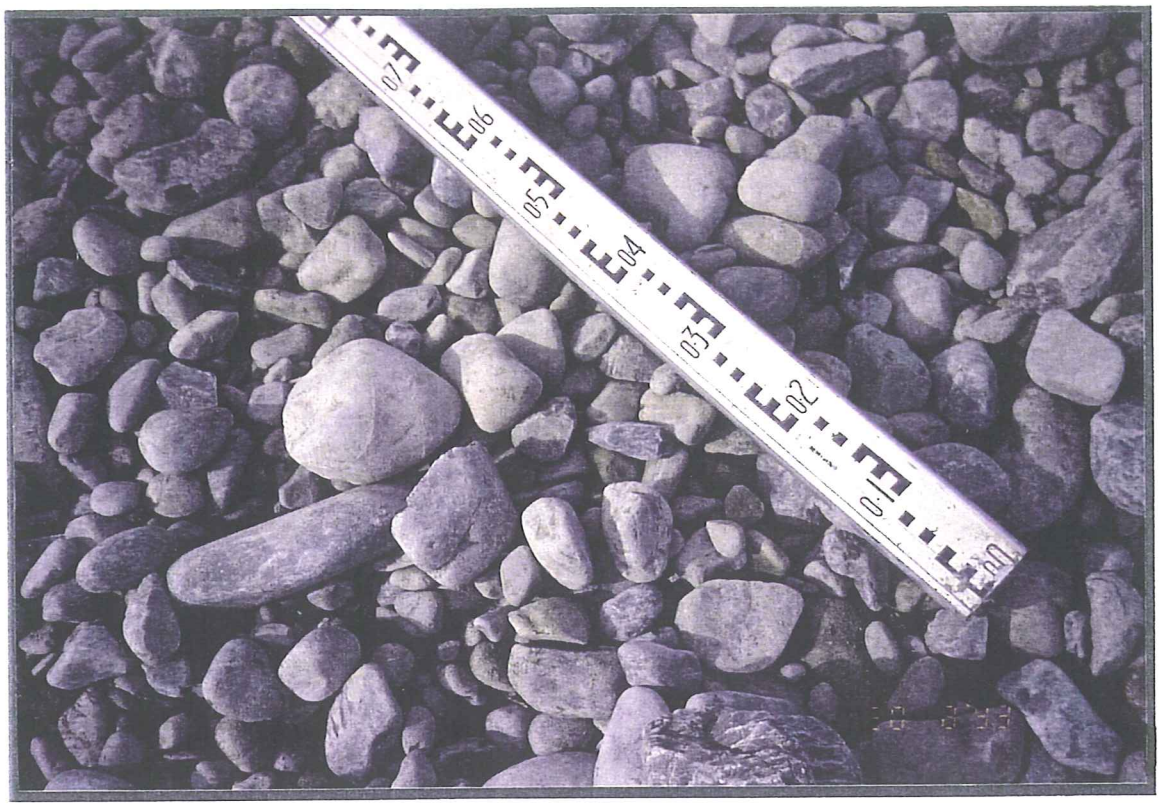
a) Excavated raked stones in a pond on the Tekapo Delta.



b) Barley Straw, 3 months after it was added to ponds at Ben Ohau Seepages.

Figure 8.3. Examples of the substrata in four experimental ponds.

c) Stones. The scale bar shows centimetres.



d) Typical substratum in old wetlands. This photograph was taken at Irishman's Ponds.

Figure 8.3 continued.

black stilts feed), and rotating it so that it cut 5 cm into the substratum. The bottom edge of the cylinder cut through most straw, detritus and vegetation. A sieve (0.8 mm mesh, 200 mm diameter, 50 mm deep) was passed quickly and repeatedly through the water within the cylinder using one hand, while the water and substratum were stirred vigorously with the other hand. The sieve was emptied every few seconds into a bucket attached to the outside of the cylinder. Soft or loose substratum, to a maximum depth of 5 cm (approximate depth to which black stilts probe) was also removed and placed in the bucket. Gradations on the bucket allowed a double check of the volume of substratum removed; 0.1 m^2 to 5 cm depth yields 5 litres. Preliminary tests of this method showed that it effectively sampled invertebrates in a precisely delimited area and in a wide range of substrata, including mud, macrophytes and stones (Appendix 4). The pooled subsamples were split in the field by thoroughly mixing them in a 20 litre bucket and pouring them through a sample splitter. The splitting method produced a representative sample that consisted of one quarter of the pooled subsamples (Appendix 8). Stones were rinsed and discarded before subsamples were pooled and split. Coarse detritus that did not pass through the splitter was quartered by eye using guidelines on the bottom of the splitter. Tests of the splitting method showed that it provided more representative estimates of biomass than single samples (Appendix 8). The final sample was washed on site and preserved by adding 30% formalin to the wet samples, to give a final formalin concentration of *c.*15%.

Samples were sorted within 12 weeks of collection, and invertebrates were identified as far as practical, using the keys of Winterbourn (1973), Winterbourn and Gregson (1989) and McFarlane (1990). During sorting, invertebrates were separated into the four 'food groups' defined above. Each group was dried separately at 60° C, to constant weight, and weighed to the nearest milligram. Body mass of hard-shelled invertebrates (*i.e.* mass excluding shells and cases) was estimated by multiplying total mass by 0.25, except for total mass of *Potamopyrgus antipodarum*, which was multiplied by 0.10 (Michaelis 1974). Conversion factors for all other species were determined by weighing shells, cases and bodies of subsamples of animals.

Measurement of site conditions

Maximum-minimum thermometers were placed within the substratum in one pond at each site, and read and reset every 3 months. Spot measurements of dissolved oxygen concentration, pH, temperature and conductivity were also made on each sampling occasion. Spot measurements were made within one hour at any particular site, and are therefore directly comparable within sites. However, among-site comparisons should be made with caution because conditions at sites

sampled on different days are likely to have been affected by weather conditions. Percentage vegetation 'cover' (%COVER) in each pond was visually estimated on each sampling occasion. Vegetation typically consisted of sparse clumps of rushes or sedges, which, strictly speaking, cover only a very small area. However, for the purpose of these experiments, plants were considered to provide continuous cover if they were closer to each other than 30 cm.

As well as measuring conditions within the ponds, I measured three terrestrial site variables, which were used to develop exploratory models (see below). The composition of the substratum in which each pond was constructed was characterized in two ways: first, the percentage area occupied by particles less than 2 mm in diameter (%FINES) in the substratum beside each pond was estimated by eye using a subdivided quadrat. Second, the percentage ash-free dry mass of fine particulate organic matter (%FPOM) was measured by ashing substratum samples at 550° C for 2.5 hours. (FPOM comprises organic particles between 0.5 μm and 1 mm in diameter; Merritt *et al.* 1984.) The amount of terrestrial vegetation beside each pond was estimated by scoring each pond on a scale of 0 to 10, where 0 indicates no vegetation and 10 indicates dense, tall grasses and tussocks.

Statistical Analysis

Experimental design at the six sites is summarized in Table 8.2. Five replicate ponds were constructed for each substratum manipulation that was investigated at each site (with four exceptions - see Table 8.2). Each experiment was initially designed as a repeated measures analysis of variance in which each pond was to be sampled 3 and 15 months after pond construction. However, ponds at only three of the six sites (Kevin's Diversion, Ben Ohau Seepages and Mick's Lagoon) were able to be sampled on both occasions; ponds at two sites (Tekapo Delta and Irishman's Ponds) were damaged or inaccessible because of flooding at 15 months, and ponds at one site (Aviary Wetland) were not full at 3 months. The three sites sampled once were therefore analysed as 1-factor ANOVAs. For each pond, five response variables were measured; biomass of the four food types defined above, and total invertebrate biomass. Each response variable was analysed as a separate ANOVA.

Homogeneity of sample variances was tested using Cochran's C test (following Underwood 1981) and sample distributions were inspected graphically for deviations from normality. Where necessary, data were transformed by $\log_{10}(x)$, $\log_{10}(x + 1)$ or $\sqrt{(x + 0.5)}$ transformations, where x = biomass in mg.m^{-2}. Biomass data from the three sites that were sampled twice were analysed using univariate repeated measures ANOVA, with substratum and time as the two factors. Data from the

three sites that were sampled once were analysed using 1-factor ANOVAs with substratum as the factor. Kruskal-Wallis non-parametric ANOVAs were used to analyse data that could not be transformed to meet the assumptions of parametric ANOVA. Tukey's T-tests were used to compare means following statistically significant ($\alpha < 0.05$) parametric ANOVAs. Non-parametric Tukey-type comparisons (Zar 1984) were used to compare medians following significant non-parametric ANOVAs. Minimum differences between means that these experiments would detect, at the 5% significance level with 80% power, were estimated using Pearson and Hartley's (1951) tables, following Zar (1984). Statistical comparisons were restricted to substrata within sites and between times.

Ordination by non-metric multidimensional scaling (NMDS) was used to explore differences among invertebrate communities in samples taken from different substrata and sites, and to describe changes in communities at the three sites that were sampled twice. NMDS was performed on presence-absence data using Jaccard's coefficient (following Shi 1993) and using SAS (SAS Institute Inc. 1989).

Multiple regression was used to develop models, for each food type and for total invertebrate biomass. The models used five predictor variables that could be measured before wetlands were developed. These were: %FINES, %FPOM, terrestrial vegetation score, presence or absence of straw, and mean biomass of each food type in old ponds. Presence or absence of straw was included as a predictor variable because the results of these experiments suggested that it has good potential as a management technique. Stepwise regression was used to develop models, using the computer programme STATISTIX (Siegel 1992). Only variables that increased the coefficient of determination by at least 3%, and were statistically significant, were included in the models. %FINES was arcsine square root-transformed, and %FPOM was $\log_{10}$-transformed. Residuals were inspected graphically.

RESULTS

Composition of the fauna

Fifty six taxa were found in the 176 samples taken during the course of these experiments. The 29 most commonly occurring taxa, arbitrarily defined as those that occurred in more than 10 out of 176 samples, are listed in Table 8.3. Aquatic Oligochaeta and *Chironomus zealandicus* were the most commonly occurring taxa, and were present in 89% and 80% of samples, respectively. They were also the most abundant taxa, and were present at mean (± SE) densities of 1452 m^{-2} (± 18 m^{-2}) and 900 m^{-2} (±15 m^{-2}). The next most commonly occurring taxa were much less abundant than Oligochaeta and Chironomidae. They were: the waterboatman, *Sigara* sp. (mean density ± SE: 76 ± 13 m^{-2}), and larvae of the Tanypodinae (Chironomidae) (39 ± 6 m^{-2}); the damselfly, *Xanthocnemis zealandica* (35 ± 5 m^{-2}), and the stony-cased caddisfly, *Hudsonema amabilis* (91 ± 21 m^{-2}). Less widespread taxa were also less abundant, on average, than the above taxa.

Substratum effects

Statistical significance of ANOVAs and estimated minimum detectable differences ($\alpha = 0.05$, $\beta = 0.80$) between means at all sites are summarized in Table 8.4. Figure 8.4 shows mean biomass of the four food types, and mean total biomass, in each substratum at each site; raw biomass data are listed in Appendix 9. Statistically significant differences among means or medians are discussed below. For clarity, all scales use the same units, $g.m^{-2}$ dry mass, although analyses were performed on data transformed by several methods, as well as on raw data. Note that different sites have different scales. Table 8.5 shows mean and pooled taxonomic richness in each substratum, and changes in taxonomic richness over time, at those sites sampled twice.

Tekapo Delta

Mean invertebrate biomass in all substrata on the Tekapo Delta (Fig. 8.4a) was lower than at all other sites, except Irishman's Ponds (Fig. 8.4c). Oligochaeta comprised most of the mean biomass in all substrata, except excavated raked stony ponds, in which mean oligochaete biomass, (and therefore mean total biomass), was significantly lower than in old, excavated mud and flooded stony ponds. Mean (or median) biomass of other food types was very low in all substrata, with the exception of median chironomid biomass (0.50 $g.m^{-2}$), which was significantly higher in excavated mud than in than in all other substrata. Mean nekton biomass was significantly greater in flooded stony ponds than in old and excavated mud ponds. Densities of most taxa were very low; only

Table 8.3. The number of samples in which the 29 most widespread taxa occurred. For brevity, the 27 taxa that were found in fewer than 10 samples are excluded. Some ponds were sampled on two occasions; Taxa that were found in more or fewer of the samples taken after 15 months than those taken after 3 months are indicated by + and -, respectively. Statistical significance of changes in occurrence of each taxon were tested using the χ^2 test of independence. n.s. $P > 0.10$, † $P < 0.10$, * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

Taxon	All ponds, both times N= 176	Ponds that were sampled twice			
		3 months N = 53	15 months N = 55	Change in occurrence of taxa	Statistical significance of change
OLIGOCHAETA	157	45	53	+	*
DIPTERA					
Chironomus zealandicus	141	46	40	-	†
Tanypodinae	91	15	33	+	***
Ceratopogonidae	53	8	28	+	***
Muscidae	30	9	8	-	n.s.
Stratiomyidae	29	8	6	-	n.s.
Culicidae	15	1	10	+	**
Ephydrella sp.	11	7	2	-	†
HEMIPTERA					
Sigara sp.	104	38	46	+	†
Anisops sp.	17	9	8	-	n.s.
ODONATA					
Xanthocnemis zealandica	88	21	36	+	**
COLEOPTERA					
Liodessus sp.	58	20	16	-	n.s.
Elmidae	49	5	19	+	**
Berosus sp.	43	2	29	+	***
Rhantus pulverosus	39	17	10	-	†
Antiporus strigosulus	29	24	4	-	***
TRICHOPTERA					
Hudsonema amabilis	69	7	37	+	***
Paroxyethira sp. 2	36	11	20	+	†
Paroxyethira hendersoni	25	9	3	-	†
Oxyethira albiceps	27	16	4	-	**
Polyplectropus sp.	28	9	18	+	†
Triplectides cephalotes	25	7	10	+	n.s.
EPHEMEROPTERA					
Deleatidium spp.	22	9	9	=	n.s.
MOLLUSCA					
Physa acuta	61	14	24	+	†
Lymnaea tomentosa	43	5	26	+	***
Potamopyrgus antipodarum	37	5	17	+	**
Sphaerium novaezelandiae	33	9	17	+	†
Gyraulus corinna	23	4	11	+	†
AMPHIPODA					
Paracalliope sp.	11	9	2	-	*

Table 8.4. Summary of statistical significance of analyses of variance. Estimated minimum detectable differences ($\alpha = 0.05$, $\beta = 0.80$) are shown for substratum and time (δ_S and δ_T, respectively). Note that values for δ_S and δ_T are in the same units as those on which the analyses were performed. Analyses were performed on $\log_{10}(x)$ or $\log_{10}(x + 1)$ transformations of the raw data (in mg per 0.1 m^2) unless otherwise indicated. See text for further details of experimental design, data transformations, calculations of detectable differences, and comparisons of means and medians.

Site	Source of variation & δ_S and δ_T	Oligochaeta	Chironomidae	Nekton	Hard-shelled	Total
Tekapo Delta	Substratum	0.0003[a]	0.025[b]	0.057	0.0009[b]	0.0009
	δ_S	0.70	-	1.34	-	0.82
Aviary Wetland	Substratum	0.57	0.048	0.0001[c]	0.004	0.075[c]
	δ_S	1.99	1.18	63	1.27	317
Irishman's Ponds	Substratum	<0.0001	0.13	0.015	0.0003	0.003
	δ_S	0.37	1.12	1.29	1.12	1.03
Kevin's Diversion	Substratum	<0.0001	0.31	0.028[a]	0.0002[b]	0.035
	Time	0.003	<0.0001	<0.0001[a]	<0.0001[b]	0.01
	Sub × Time	0.13	0.35	0.084	0.19[b]	0.14
	δ_S	0.46	0.67	3.79	-	0.42
	δ_T	0.26	0.38	2.15	-	0.24
Ben Ohau Seepages	Substratum	0.002	<0.0001	0.067	<0.0001	0.003
	Time	0.76	<0.0001	0.002	0.008	0.073
	Sub × Time	0.39	0.007	0.0005	0.002	0.23
	δ_S	0.97	0.66	0.48	0.48	0.42
	δ_T	0.55	0.37	0.29	0.27	0.24
Mick's Lagoon	Substratum	0.67[c]	<0.0001[b]	0.34[c]	0.022[b]	0.26[c]
	Time	0.005[c]	0.15[b]	0.84[c]	0.91[b]	0.045[c]
	Sub × Time	0.62[c]	0.42[b]	0.81[c]	0.076[b]	0.95[c]
	δ_S	261	-	37	-	395
	δ_T	273	-	39	-	414

[a] $\sqrt{(x + 0.5)}$ transformation applied.

[b] ANOVA performed on ranks.

[c] No transformation necessary, analysis performed on raw data (in mg per 0.1 m^2).

Table 8.5. Mean and pooled taxonomic richness in samples taken from each substratum at each site (n=5 unless otherwise indicated). Changes in taxonomic richness at sites that were sampled twice are also shown: 'Losses' are the numbers of taxa present in pooled samples taken 3 months after pond construction but absent from samples taken after 15 months. 'Gains' *vice versa*. Substratum acronyms follow Table 8.2.

	Sub-	3 months		15 months		Losses	Gains	Net
Site	stratum	Mean (SE)	Pooled	Mean (SE)	Pooled			change
Kevin's	KEB	10.0 (1.38)	21	14.6 (1.21)	21	8	8	0
Diversion	KE	9.0 (1.14)	19	14.4 (0.51)	23	5	9	+4
	KF	7.8 (1.16)	18	13.8 (1.46)	21	6	9	+3
	KES	11.2 (1.32)	24	15.6 (1.50)	27	7	10	+3
Ben Ohau	BO	9.6 (0.98)	16	10.4 (1.94)	20	4	8	+4
Seepages	BEB	7.4 (0.51)	11	7.6 (0.51)	16	5	10	+5
	BES	3.8 (0.86)	10	7.2 (0.37)	12	3	5	+2
	BE	4.6 (0.75)	10	7.6 (0.75)	17	4	11	+7
Mick's	MO	8.0 (0.89)	17	6.4 (1.63)	14	8	5	-3
Lagoon	MEB	7.0 (0.58)	9 (n=3)	8.4 (0.81)	14	1	6	+5
	ME	7.6 (0.93)	13	8.6 (0.81)	16	4	7	+3
Tekapo	TO	3.4 (0.74)	7		-	-	-	-
Delta	TRB	4.4 (0.75)	12		-	-	-	-
	TEM	4.0 (0.77)	9		-	-	-	-
	TFM	5.8 (1.36)	14		-	-	-	-
	TR	6.2 (1.24)	15		-	-	-	-
	TFS	9.8 (1.16)	20		-	-	-	-
Aviary	AO		-	8.2 (1.07)	13	-	-	-
Wetland	AF		-	10.0 (1.45)	17	-	-	-
	AFB		-	12.0 (0.91)	18 (n=4)	-	-	-
	AFS		-	8.3 (0.85)	15 (n=4)	-	-	-
Irishman's	IO	9.2 (0.37)	14		-	-	-	-
Ponds	IERS	5.3 (0.95)	11 (n=4)		-	-	-	-
	IEB	5.4 (0.87)	11		-	-	-	-
	IE	6.0 (2.10)	16 (n=6)		-	-	-	-

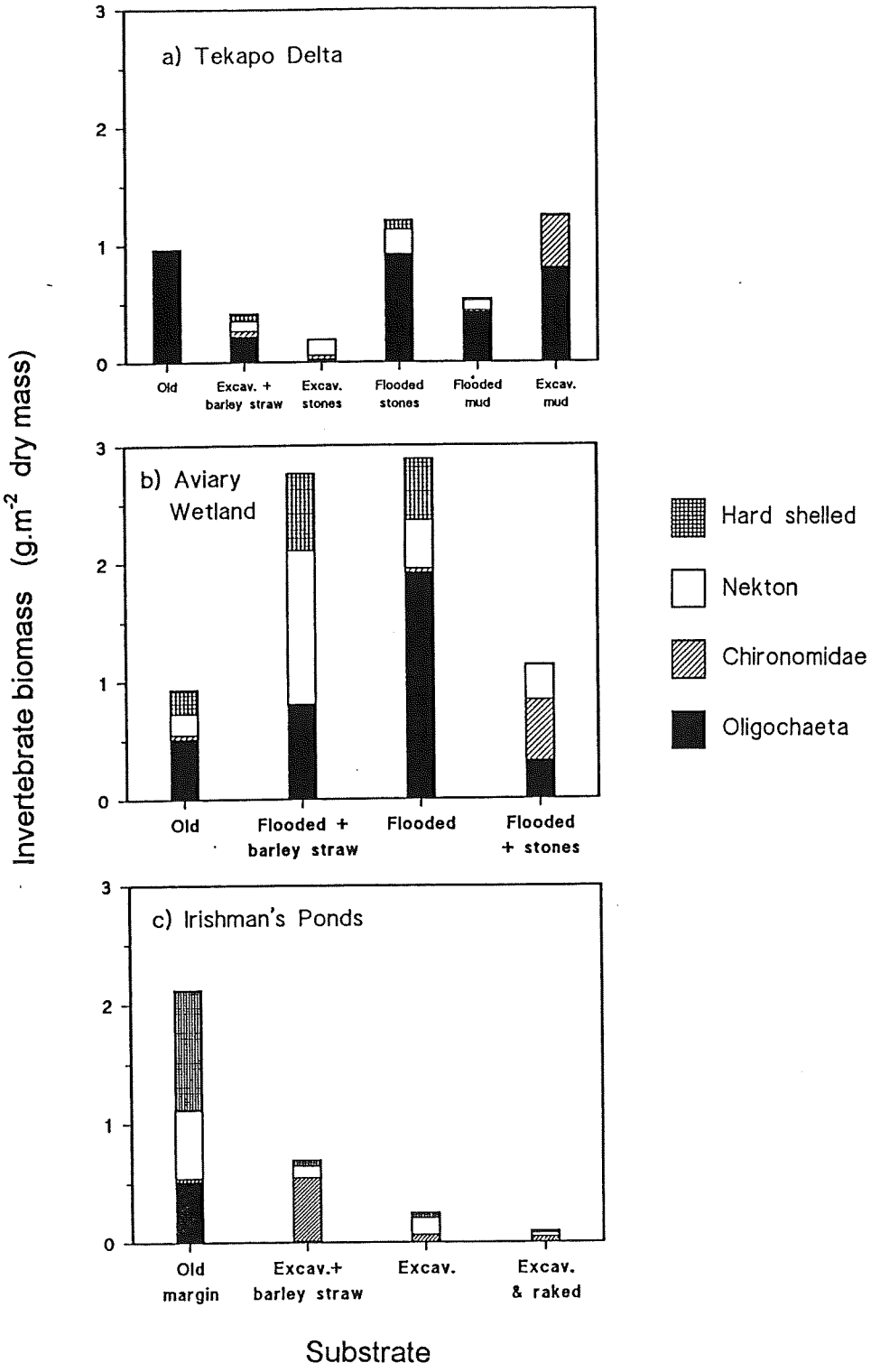


Figure 8.4. Mean invertebrate biomass at the experimental sites. See text for definitions of food types. For sites that were sampled twice, the left and right hand bars represent biomass at 3 and 15 months, respectively, after pond construction. Results of ANOVAs of these data, and estimated minimum detectable differences are summarized in Table 8.4. Statistically significant differences are discussed in the text. Excav. = excavated

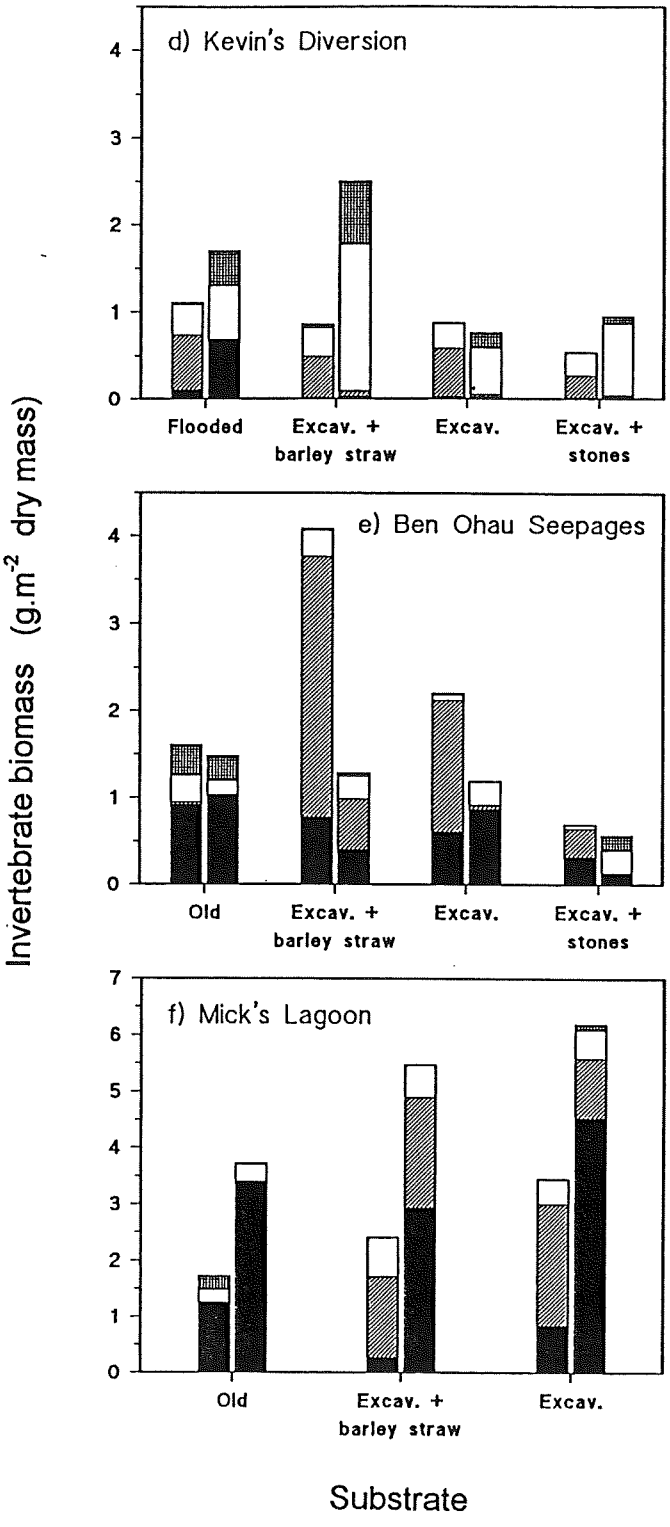


Figure 8.4 continued. Note different scales of the Y-axes.

Oligochaeta and *Chironomus zealandicus* occurred at mean densities greater than 50 m^{-2}. With the exception of flooded stony ponds, mean taxonomic richness was low in samples taken from the Tekapo Delta compared to samples taken at other sites (Table 8.5). Only 3.4 (±0.74 SE) taxa were present, on average, in samples taken from old ponds on the Tekapo Delta. Ordination of Tekapo Delta ponds showed that communities in old ponds and flooded stony ponds formed two reasonably isolated and discrete clusters in ordination space, whereas communities in the other substrata overlapped and were more widely scattered.

Aviary Wetland

The quantity and composition of food types among the substrata at Aviary Wetland was the most variable of all sites. Flooded stony ponds contained significantly lower hard-shelled biomass, and significantly more chironomid biomass, than other substrata (Fig. 8.4b). Flooded plus barley straw ponds contained significantly greater nekton biomass than other substrata. Mean total biomass in samples from flooded plus barley straw (2.76 $g.m^{-2}$) and flooded ponds (2.88 $g.m^{-2}$) at Aviary Wetland was exceeded only in samples taken from barley straw ponds at Ben Ohau Seepages and most substrata at Mick's Lagoon. However, neither oligochaete nor total biomass differed significantly among ponds at Aviary Wetland (although the ANOVA of total biomass approached significance at the 5% level; $P = 0.075$). *X. zealandica* and *H. amabilis* were particularly abundant in flooded plus barley straw and flooded ponds at Aviary Wetland, and their abundance accounts for the relatively high nekton and hard-shelled biomass in those substrata. Ordination of Aviary Wetland communities showed that barley straw ponds formed the tightest cluster, in the centre of the ordination space, but that communities in all substrata overlapped substantially.

Irishman's Ponds

Samples from newly created ponds at Irishman's Ponds (Fig. 8.4c) contained lower invertebrate biomass than samples from newly created ponds at other sites, with the exception of three types of ponds on the Tekapo Delta, and one at Ben Ohau Seepages. At Irishman's Ponds, samples from newly created ponds all contained extremely low biomass of Oligochaeta, hard-shelled invertebrates and nekton (all means <0.15 $g.m^{-2}$). However, in samples from the margins of existing wetlands ('old margin' in Fig. 8.4c) these food types were present in significantly greater quantities than in all or some of the newly created ponds. Mean chironomid biomass was also very low in excavated, and excavated and raked ponds, and although it was greater in excavated plus

barley straw ponds, this difference was not statistically significant. Mean (± SE) total biomass in old margins was 2.12 (± 0.34) $g.m^{-2}$, and was significantly greater than in excavated, and excavated and raked ponds, but was not significantly greater than in excavated plus barley straw ponds.

Mean densities of most taxa in samples from Irishman's Ponds were very low. Only seven taxa were present at mean densities greater than 50 per m^2. These were Oligochaeta (mean ± SE: 852 ± 184), *Potamopyrgus antipodarum* (992 ± 234), *Physa acuta* (116 ± 35) and *X. zealandica* (70 ±18) in old ponds; *C. zealandicus* (702±575 SE), Tanypodinae (104 ±60) and *Physa acuta* (56 ± 15) in excavated + barley straw ponds, and *Paroxyethira hendersoni* (108 ± 72) in excavated ponds. Samples from old ponds contained similar taxa and were clustered tightly in ordination space. In contrast, samples from newly created ponds were mainly composed of different subsets of the communities in old ponds, and were scattered and intermingled in ordination space. Mean taxonomic richness was highest in old ponds (9.2 ± 0.37 taxa; Table 8.5). Taxonomic richness was generally lower in samples from newly created ponds at Irishman's Ponds and Tekapo Delta than in newly created ponds at other sites.

Kevin's Diversion

In contrast to all other sites, oligochaete biomass comprised only a very small proportion of invertebrate biomass at Kevin's Diversion, except in samples from flooded ponds. In flooded ponds, oligochaete biomass was significantly greater than in other substrata. Conversely, nekton biomass was relatively high in all substrata, particularly in excavated plus barley straw ponds. In these ponds, nekton biomass was significantly greater than in excavated ponds. Samples from barley straw ponds also contained significantly greater hard-shelled biomass than excavated plus stones ponds. Chironomid biomass did not differ among substrata, but was significantly lower in 15 month old ponds than in 3 month old ponds. In contrast, mean biomass of the other food types was higher 15 months after pond construction, as was mean total biomass. Thus, nekton and hard-shelled invertebrates comprised the bulk of invertebrate biomass 15 months after pond construction.

The composition of invertebrate communities changed more dramatically at Kevin's Diversion than at other sites (Fig. 8.5). Three months after pond construction, the communities in different substrata formed distinct but overlapping clusters in ordination space. Fifteen months after pond construction, the composition of these communities had changed and converged strongly (Fig. 8.5). These changes are attributable to a high turnover of taxa; 5-8 taxa were present in samples taken

after 3 months, but were absent from samples taken after 15 months, while 8-10 'new' taxa were found in samples taken after 15 months (Table 8.5). Mean and pooled taxonomic richness in samples taken from Kevin's Diversion increased over time, and were higher than in samples taken from other sites.

Ben Ohau Seepages

Invertebrate biomass in newly created ponds at Ben Ohau Seepages was dominated by Chironomidae at 3 months (Fig. 8.4e). However, chironomid biomass decreased significantly with time, and 15 months after pond construction, was low in all substrata, except excavated plus barley straw. A similar decrease in chironomid biomass occurred at Kevin's Diversion, although at that site, biomass also declined in barley straw ponds. At Ben Ohau Seepages, like Kevin's Diversion, biomass of nekton and hard-shelled invertebrates increased over time. In old ponds, hard-shelled invertebrate biomass was significantly greater, and oligochaete, chironomid and total biomass was significantly lower than in other substrata.

The composition of invertebrate communities also changed and converged over time at Ben Ohau Seepages. Three months after pond construction, communities in ponds at Ben Ohau Seepages formed three distinct clusters in ordination space. They consisted of: 1) excavated plus barley straw ponds, 2) excavated and excavated plus stones, and 3) old ponds. Old ponds were the most distinct. However, by 15 months, community composition in newly created substrata had converged on that of old ponds and had also become more like that of 15 month old ponds at Kevin's Diversion, and old ponds at Aviary Wetland (Fig. 8.5). Communities in excavated plus barley straw ponds had changed the least. The changes at Ben Ohau Seepages were characterised by the loss of several nektonic species, including the larvae of the beetle *Antiporus strigosulus* and the mayfly *Deleatidium* sp., and gains of between 5 and 11 taxa, including up to three mollusc species per pond.

Mick's Lagoon

Mean total biomass was higher in samples from Mick's Lagoon (Fig. 8.4f) than in samples from most other sites and substrata. Unlike other sites, only one significant difference occurred among substrata; old ponds had practically no chironomid biomass, while excavated and excavated plus barley straw ponds contained similar, high chironomid biomass. At Ben Ohau Seepages and Kevin's Diversion, chironomid biomass was significantly lower after 15 months than after 3 months. In contrast, at Mick's Lagoon, chironomid biomass remained at similar, high levels 15 months after pond construction. Mean nekton and hard-shelled biomass was also similar at both

times, but mean oligochaete biomass in newly created ponds increased significantly over time. The increase in mean oligochaete biomass resulted in mean total biomass increasing significantly over time.

Communities in newly created ponds at Mick's Lagoon were similar to each other, but distinctly different from those in old ponds 3 months after pond construction. Fifteen months after pond construction, communities in both types of newly created ponds had become more like those in old ponds. However, the change in community composition was greater in excavated ponds than in excavated plus barley straw ponds. Changes in community composition occurred more slowly at Mick's Lagoon than at Ben Ohau Seepages and Kevin's Diversion. However, the direction of change was similar; communities in newly created ponds at all sites moved toward the left of the ordination space in Figure 8.5.

Ordination of all sites

Although communities in individual ponds were represented by points that were scattered in ordination space, clear trends were evident in the way communities changed through time. These are represented in Figure 8.5 by plotting the average positions of the replicate ponds for each combination of substrata, time and site. The greatest differences in communities were among newly created ponds at different sites, 3 months after pond construction. Although community composition in old ponds varied among sites, this variation was much smaller than that among newly created ponds, as is evident from the location of old ponds in the same general region of ordination space (Fig. 8.5). Exceptions to this trend were the depauperate communities of old Tekapo Delta 'ponds', which were located in bays at the edge of Lake Benmore. After15 months, communities in newly created ponds became more like those in old ponds as is evident by the shifts to the left in Figure 8.5. The convergence of pond communities was mainly a consequence of changes in the beetle fauna, and an accumulation of taxa, particularly Mollusca and *H. amabilis*, in newly created ponds (Table 8.3). Although new ponds must become like old ponds over time, Figure 8.5 shows that the rate of change varies among sites.

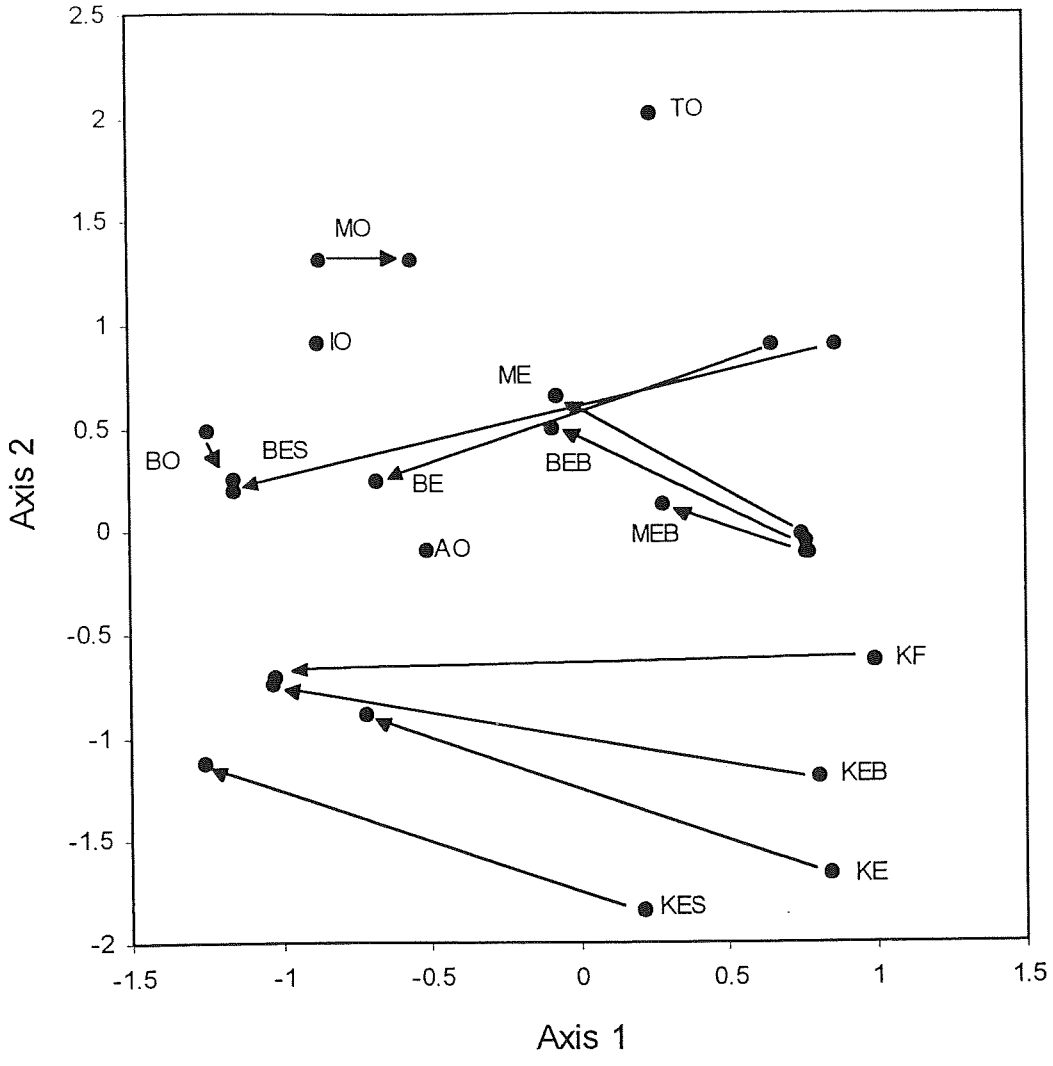


Figure 8.5. Non-metric multidimensional scaling plot showing changes in community composition of experimental ponds in the Upper Waitaki Basin. Only those sites that were sampled on both sampling occasions, and all old substrata, are shown. For clarity, centroids of the replicate groups of ponds (n = 3-6) are plotted, rather than coordinates of all samples. That is, each point represents one combination of site, substrata, and time. Arrows indicate the changes in composition that occurred between 3 and 15 months after pond construction. Acronyms for site and substratum combinations are given in Table 8.2.

Pooled biomass data

Although the biomass of the four food types varied with site and substrata, inspection of Figure 8.4 suggested trends in biomass with increasing pond age. To summarise these trends, biomass data for each food type, from all sites, were pooled and plotted against pond age (Fig. 8.6). Old ponds were between *c.* 60 and *c.* 120 months old, but, for clarity, are plotted against 100 months in Figure 8.6. Although total biomass remained relatively constant through time, the relative contribution of the different food types to total biomass changed dramatically. At first, chironomid larvae comprised a large proportion of the biomass, but their contribution to total biomass declined rapidly, while oligochaete biomass increased with pond age. Hard-shelled invertebrate biomass also tended to increase with pond age, but generally contributed less than one tenth of total biomass. Nekton biomass increased with pond age up to 15 months, but was lower in 100 month old ponds than in 15 month old ponds.

Physico-chemical conditions

At each site, oxygen concentration, pH and conductivity were similar in all ponds irrespective of substratum (Table 8.1). Water temperatures varied by as much as 16° C (measured over one hour on the day ponds were sampled) among ponds at each site (Table 8.1), but these variations were not associated with any particular substratum. Water temperature maxima were highest at Irishman's Ponds, Ben Ohau Seepages and Mick's Lagoon. Conductivity ranged from 18 $\mu S.cm^{-1}$ at Ben Ohau Seepages to 111 $\mu S.cm^{-1}$ Tekapo Delta.

Substratum composition and vegetation within and adjacent to ponds varied among sites and substrata (Table 8.6). The greatest differences were in %FINES, which ranged from < 5% in stony ponds, to 100% in ponds at muddy sites. Percentage FPOM was highest at Mick's Lagoon and Aviary Wetland and lowest at Irishman's Ponds, in stony ponds on the Tekapo Delta, and in ponds to which stones had been added. The percentage of vegetation cover in ponds was also highly variable, but tended to increase with pond age.

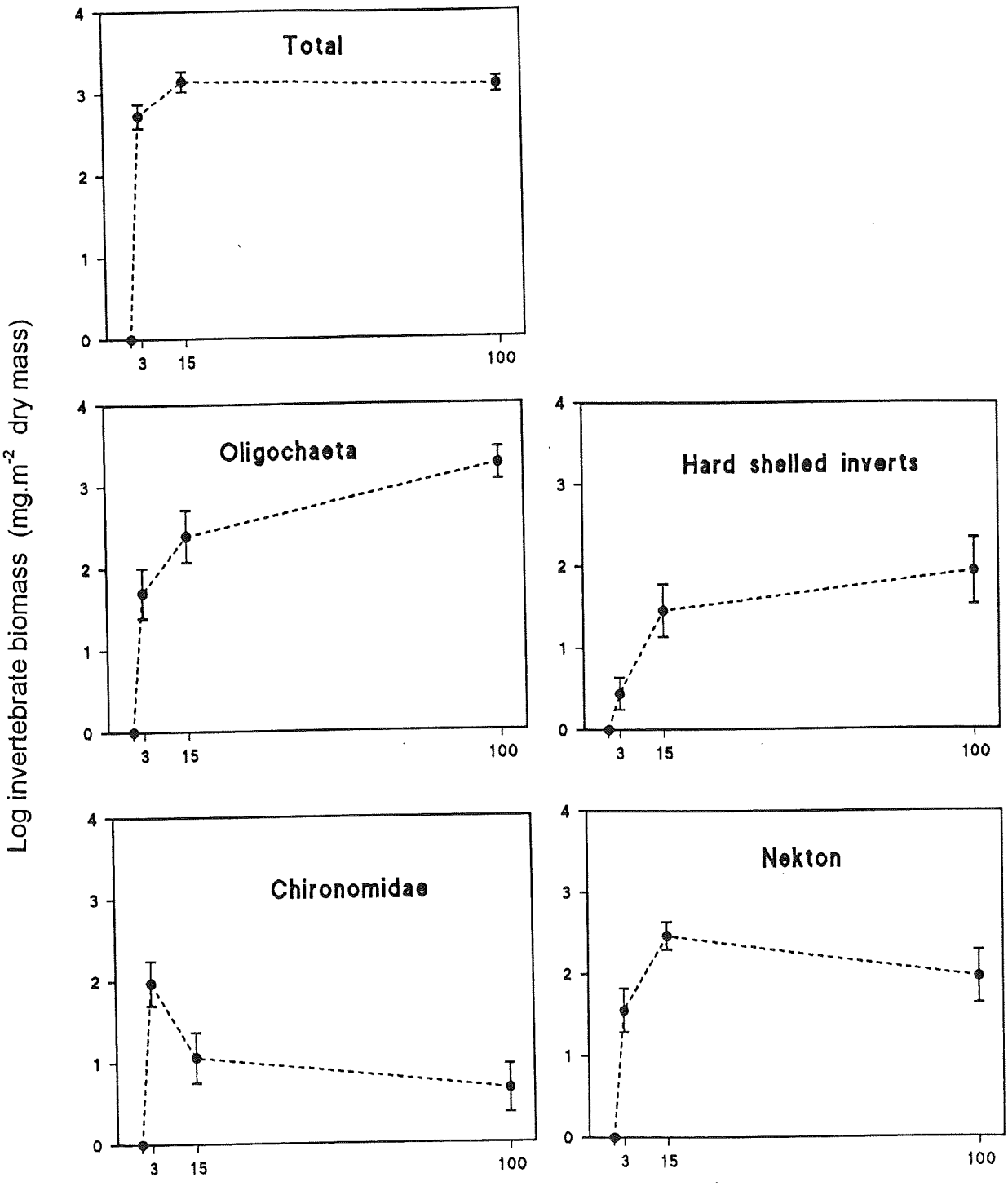


Figure 8.6. Changes in mean biomass of invertebrate food types, in different aged ponds, when all experimental data were pooled. Old ponds were assumed to be 100 months old. The number of samples taken from 3, 15 and 100 month old ponds were 83, 58 and 35, respectively. Vertical bars represent 95 % confidence intervals.

Table 8.6. Substratum and vegetation conditions in ponds ('in') and in adjacent terrestrial substrata ('out'). Variables are defined in the text. Substratum codes follow Table 8.2.

Site	Substratum	% FPOM in	% FPOM out	% FINES in	% FINES out	% COVER in, 3 mths	% COVER in, 15 mths	Vegn. out
Tekapo Delta	TO	3.18	-	79	-	1	-	3.8
	TRB	0.01	-	0	-	0	-	1.4
	TEM	4.38	-	100	-	10	-	2.8
	TFM	2.63	-	91	-	7	-	3.0
	TR	0.02	-	2	-	0	-	1.6
	TFS	0.30	-	9	-	1	-	2.0
	mean	1.75	-	47	-	3	-	2.4
Aviary Wetland	AO	5.48	12.78	98	94	-	6	4.2
	AF	11.57	9.50	100	68	-	52	4.2
	AFB	23.25	11.29	100	78	-	36	4.3
	AFS	0.29	11.58	3	84	-	50	4.8
	mean	9.97	11.27	78	81	-	35	4.4
Irishman's Ponds	IO	5.11	-	60	-	50	-	3.6
	IE	<1.0	0.82	25	33	3	-	2.0
	IER	<1.0	2.85	18	57	4	-	2.3
	IEB	<1.0	2.42	25	68	2	-	2.0
	mean	<2.0	2.03	32	53	15	-	2.5
Kevin's Diversion	KE	2.16	1.18	42	98	0	1	6.6
	KF	6.36	4.92	88	99	40	28	7.6
	KEB	1.83	1.50	44	100	0	1	5.0
	KES	0.07	0.00	1	93	0	2	5.8
	mean	2.61	1.90	44	98	10	8	6.3
Ben Ohau Seepages	BEB	3.31	4.37	91	91	0	7	8.4
	BES	1.33	1.31	27	90	0	44	9.2
	BE	4.85	4.10	93	93	0	13	7.8
	BO	3.37	-	98	98	56	56	8.6
	mean	3.22	3.26	77	77	30	30	8.5
Mick's Lagoon	MO	12.82	-	100	100	75	74	5.0
	MEB	26.06	12.83	100	100	10	34	5.0
	ME	29.94	13.78	100	100	10	36	5.0
	mean	22.94	13.14	100	100	32	48	5.0
All sites	mean	7.08	6.32	63.0	81.8	18	12	4.9

Exploratory models

Models that related invertebrate biomass, 3 or 15 months after pond construction, to initial site conditions were all statistically significant (Table 8.7). However, only the models for Oligochaeta, Chironomidae and total biomass explained a reasonable portion of the variation in the data ($0.23 < r^2 < 0.69$). %FINES and the presence or absence of barley straw were the most useful predictors, occurring in 9 and 4 out of 12 models, respectively. Mean biomass of any particular food type in existing ponds was not usually a good predictor of biomass of that food type in newly created ponds.

Table 8.7. Exploratory multiple regression models showing relationships between invertebrate biomass and site conditions that could be measured before pond construction. Models were developed from biomass (mg per 0.1 m^2 dry mass) of four food types at 3 and 15 months after pond construction. Excl. indicates that a variable was not considered as a predictor for that particular model. Significance of coefficients: n.s. $P > 0.05$, * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

					Coefficients					
Food type	Pond age (mths)	$r^2_{adj.}$	P	N	Intercept	Arcsine %FINES	Log_{10} %FPOM	Terr. Vegn	Presence of Straw	Old biomass
Log_{10} (x+1)	3	0.24	<0.0001	76	-2.09***	0.96***	-	-	-	Excl.
Oligochaeta	3	0.37	<0.0001	56	-1.64***	0.56**	-	-	-	2.42***
	15	0.44	<0.0001	45	0.23 n.s.	1.06***	-	-	-	-
Log_{10} (x+1)	3	0.42	<0.0001	69	-1.69***	-	0.34**	0.15***	0.57**	-
Chironomidae	15	0.34	0.0001	45	0.44***	-	0.31*	-	0.74***	-
Log_{10} (x+1)	3	0.05	0.0255	83	-1.44***	-	-	-	0.54*	-
Nekton	15	0.08	0.0330	45	1.88***	-0.24*	-	-	-	-
Log_{10} (x+1)	3	0.11	0.0060	76	-2.25***	-0.36*	-	-	0.45*	-
Hard-shelled	15	0.11	0.0157	45	1.29***	-0.44*	-	-	-	-
Log_{10} (x)	3	0.31	<0.0001	76	-0.71***	0.32***	-	0.06**	-	-
Total	15	0.69	<0.0001	25	1.31***	0.33*	-	-	-	2.3***
	15	0.23	0.0006	45	1.83***	0.34***	-	-	-	Excl.

DISCUSSION

The principal aim of these experiments was to compare the effects of substratum additions and construction methods on the quantity and composition of aquatic invertebrates in artificial ponds at six sites in the Upper Waitaki Basin. The results support two levels of inference: at the local level, they enable strong predictions to be made about the potential food supplies in future wetlands at the six sites investigated. More generally, they show that although substratum additions and construction methods can affect the type and amount of invertebrates in wetlands, these effects vary from site to site and are unlikely to persist for more than one or two years.

It seems reasonable to assume that local, site-specific field experiments will provide good predictions of the type, amount and rate of development of food supplies in future wetlands at the particular sites investigated. Therefore, local managers should develop wetlands at those sites, and using those methods, which these experiments indicate will provide the best food supplies for black stilts. Although food preferences of black stilts have received little attention, current knowledge (Chapters 5, 10 and 11) strongly suggests that in lentic habitats they are most likely to forage where chironomid and nekton biomass is high. Among the sites investigated in this study, the highest quantities of these food types, at least for the first two breeding seasons, would be provided by constructing wetlands at Mick's Lagoon, Ben Ohau Seepages and Kevin's Diversion. The substrata most suitable for enhancing the biomass of these food types would be provided by excavating ponds and adding barley straw at Ben Ohau Seepages and Kevin's Diversion. At Mick's Lagoon, the construction of wetlands by excavation, without substratum additions, should result in high quantities of Chironomidae and reasonable quantities of nekton. Future wetlands at Aviary Wetland are likely to be less attractive to black stilts than those at the above three sites, because they can be expected to support relatively low chironomid biomass. However, if wetlands at Aviary Wetland are constructed by flooding and adding barley straw they should provide good quantities of nekton, and be attractive to black stilts. None of the substrata at Irishman's Ponds or Tekapo Delta are likely to provide more abundant and suitable food supplies for black stilts than existing wetlands with one exception: wetlands excavated in muddy areas on the Tekapo Delta should provide reasonable quantities of Chironomidae.

As well as indicating the amount and type of food supplies that wetlands are likely to provide, my experiments show that food supplies develop rapidly in newly created wetlands. Ponds were constructed at the end of winter, before insect oviposition, and by the end of spring, invertebrate biomass in most ponds was at least as great as, and often much greater than that in several lentic

habitats at which black stilts have nested (Chapter 6). The food in most ponds was highly suitable for black stilts; nekton and chironomid biomass were high compared to lentic nest sites. Moreover, black and pied stilts nested and fed at several of these sites (Chapter 11), as did several other species of birds. So long as wetlands are created early enough in spring, they should produce good food supplies in the first season.

The abundance of invertebrates in newly created wetlands has often been attributed to the habitat and food provided by flooded terrestrial vegetation (*e.g.* Paterson and Fernando 1969; Voshell and Simmons 1984; Murkin and Kadlec 1986;). In the present study, however, invertebrates were no more abundant in ponds created by flooding terrestrial vegetation than in those that were excavated, and therefore lacked flooded vegetation. The lack of any clear difference between these two types of ponds suggests that flooded terrestrial vegetation does not necessarily strongly influence invertebrate abundance. Having said that, it must be pointed out that vegetation at the sites studied here was always sparse, and presumably provided relatively low inputs of coarse organic material.

I also found that food supplies generally varied more among sites than within sites. The apparently overriding influence of 'site' therefore suggests that the most critical decision in wetland creation or modification is site selection. However, at all sites except Mick's Lagoon, food supplies were also influenced by construction method or substratum additions. Therefore, to increase the chances that artificial wetlands will provide good foraging habitat, managers should first choose the best site available, then chose the construction method and, if necessary, the kind of substratum addition that is most suited to that particular site.

How can managers chose which sites will be best for future wetland development? One way is to conduct field trials, as in this study. Field trials probably provide the best predictions of the type and amount of food that is likely to develop in artificial wetlands, and are likely to repay the effort required to run them. An alternative or complementary option is to attempt to predict, from information available before wetlands are constructed, the likely food supplies that will occur at the potential sites. The development of models that could be used to make such predictions was the second aim of this study.

Results of exploratory multiple regression suggested that information available before wetlands were constructed could be used to make coarse predictions of oligochaete, chironomid and total invertebrate biomass, but not of nekton or hard-shelled invertebrate biomass. Although the models

for Oligochaeta and Chironomidae leave 56 - 76% of the variation in $\log_{10}$ biomass 'unexplained', they provide a rough indication of the types of conditions that are likely to favour these food types. The low proportion of variation explained by the models also highlights the great variation in food supplies that managers must expect when constructing wetlands at apparently similar sites.

Not surprisingly, given their burrowing habit, oligochaete biomass tended to be greater in ponds constructed at sites with higher proportions of fine material. The usefulness of any ability to predict oligochaete biomass is unknown at present, because the influence of Oligochaeta on black stilt habitat selection is also unknown.

In contrast, sites that have abundant chironomid larvae appear to be highly attractive to black stilts (this thesis, Chapters 5 and 11; Pierce 1985). Managers should therefore construct wetlands at sites that are most likely to provide a high biomass of chironomid larvae. In my experiments, chironomid biomass was greatest in wetlands constructed at sites where the substrata included a relatively high proportion of FPOM, and a good cover of terrestrial vegetation to which barley straw had been added. These factors explained 34% and 42% of the variation in chironomid biomass in 3 and 15 month old ponds, respectively, and they should be evaluated when selecting sites for future wetland development. Regardless of initial conditions, however, comparisons of different-aged ponds suggest that chironomid biomass in most wetlands will be high only during the first one or two summers after wetland creation.

High biomass and abundance of non-predaceous Chironomidae are typical of many newly created wetlands, and are often attributed to surplus food provided by the large amount of organic material of terrestrial origin that is available in such wetlands (Nursall 1952; McLachlan 1974; Murkin *et al.* 1982; Voshell and Simmons 1984; Murkin and Kadlec 1986). The subsequent decline in chironomid biomass characteristic of many wetlands is associated with, and probably caused by, a concurrent decline in availability of organic material (Nursall 1952; Danell and Sjöberg 1982). This seemed to be the case in my experiments; the only site at which chironomid biomass did not decline was Mick's Lagoon, where %FPOM was very high compared to other sites. To sustain high chironomid biomass in artificial wetlands, managers should therefore aim to maintain the availability of FPOM. A practical way to do this would be to add CPOM in the form of barley straw, which will break down to provide FPOM. This conclusion supports the findings of Street and Titmus (1982), who found that chironomid response to barley straw additions was associated with increased food supplies, rather than increased habitat. The availability of organic material can also be maintained by alternatively cropping and flooding land on a rotation of several years

(Hands *et al.* 1991; Helmers 1992), but such a technique is likely to be impractical at many sites in the Upper Waitaki Basin. Nevertheless, draining wetlands, allowing natural revegetation by terrestrial plants, and then re-flooding, on a rotational basis, would be a technique worth further investigation in the Upper Waitaki Basin.

The regression models for nekton and hard-shelled invertebrates explained only a low proportion of the variation in the data, and do not help to predict biomass of these two food types on the basis of initial site conditions. However, the model for 3 month old ponds confirmed observations that nekton and hard-shelled biomass was greater in ponds to which straw had been added than in non-straw ponds. Thus, the addition of barley straw to artificial wetlands is likely to increase the standing crops of the all food types except Oligochaeta. It is worth noting that the effects of barley straw addition to ponds in the Upper Waitaki Basin were not as dramatic as those reported by Street (1983) for barley straw additions to gravel pits in England. The ponds investigated here were shallower and smaller than the gravel pits that Street studied and it remains to be seen just how strongly invertebrates of large artificial wetlands in the Upper Waitaki Basin will respond to additions of barley straw.

The final aim of this study was to test whether pond communities converged in composition as the ponds became more physically similar. Ordination showed that they did converge as ponds aged, principally because of an accumulation rather than a loss of taxa. Thus, whether interpreted in terms of taxonomic composition or biomass of food types, invertebrates in ponds followed similar trends at all sites investigated in this study. Initially, ponds at different sites and with different substrata varied in community composition and relative biomass of food types. However, as they aged, community composition (in terms of taxa present) converged, at varying rates. Similarly, relative biomass of the four food types tended to change in similar ways, but at rates that varied among sites.

The tendency for communities and food types to converge suggests that ongoing management will be needed, either to maintain, or to continually create, suitable wetland habitat for black stilts (and other birds) in the Upper Waitaki Basin. Nevertheless, sites, construction methods, and substratum additions, will need to be chosen carefully in order to increase the chances of abundant and suitable food supplies developing in artificial wetlands. The high chironomid biomass typical of many

newly created wetlands makes them particularly suitable habitats for many insectivorous wetland birds. Wetland management should therefore benefit from research that aims to sustain high chironomid standing crops in artificial wetlands. Future research could also profitably explore the role of different food types in habitat selection by wetland birds.

CHAPTER 9

Mick's Lagoon patch experiment

INTRODUCTION

One of the sites investigated in the pond experiment described in Chapter 8, Mick's Lagoon, had been modified in the early 1980s, to provide a larger, safer habitat for black stilts. The outflow was dammed, and some parts were excavated, to provide a greater surface area. The ponds and surrounding bog and terrestrial environs at Mick's Lagoon were protected from mammalian predators by enclosing them within an electric fence in 1981 and by trapping and shooting predators within the enclosure (Pierce 1982b). At first, the habitat enlargement and protection seemed to provide a suitable nesting habitat for black stilts. In the first five breeding seasons following this work (1982 - 1986), six black stilts nested there. However, in the subsequent 10 years (1987 - 1996), only four black stilts have nested at Mick's Lagoon (Department of Conservation unpublished data). (A Poisson regression of years since modified, on number of black stilts nesting, at Mick's Lagoon was close to statistical significance; $\chi^2 = 3.19$, $P = 0.07$).

Why the number of black stilts has tended to decline over time at Mick's Lagoon is unknown. Reasons proposed by Department of Conservation (DOC) staff, and others who have worked with black stilts, include 1) a lack of recruitment of new breeding pairs to the surrounding area, and therefore a lack of pairs available to nest at Mick's Lagoon; 2) a decline in the physical suitability of Mick's Lagoon because of vegetation growth, and 3) a decline in the abundance and/or suitability of food supplies. In this chapter, I consider food supplies at Mick's Lagoon.

The contention that food supplies have become less suitable for black stilts at Mick's Lagoon is supported by studies of wetlands elsewhere, and by the results of the pond experiments reported in Chapter 8. Recently inundated wetlands (as Mick's Lagoon was in the early 1980s) often produce an initial 'flush' of invertebrates, particularly chironomid larvae (*e.g.* Nursall 1952; Patterson and Fernando 1969; McLachlan 1974; Danell and Sjöberg 1977, 1982; Voshell and Simmons 1984; Murkin and Kadlec 1986; Reid 1985), which appear to be a preferred prey of many aquatic birds (Danell and Sjöberg 1977, 1982; Phillips 1991; Gardarsson and Einarsson 1994; Rehfisch 1994; this thesis, Chapters 3, 5, 10 and 11). Over time, however, invertebrates in wetlands may become

less suitable as food supplies for birds (Danell and Sjöberg 1982). Results from the pond experiments reported in Chapter 8 indicate that such a decline in food suitability may have occurred at Mick's Lagoon. Samples of the substratum and water column taken from excavated ponds at Mick's Lagoon contained abundant Chironomidae and nektonic invertebrates (which also appear to be favoured prey of black stilts; Chapters 3, 10 and 11). In contrast, samples from old ponds at Mick's Lagoon were dominated by oligochaete worms and the pea mussel, *Sphaerium novaezelandiae*, which may be less suitable prey for black stilts.

It seems reasonable to assume that invertebrate food supplies provided by newly excavated ponds at Mick's Lagoon are more suitable for black stilts than those of old ponds, and therefore the continual excavation of new ponds would be one way to maintain a suitable food supply. However, new ponds cannot be continually excavated at Mick's Lagoon (or elsewhere) because the resources (money and suitable land) available are limited. For example, at Mick's Lagoon most of the area owned by DOC, and protected by the electric fence, has already been excavated or inundated.

An alternative to creating new habitat may be to manipulate existing wetlands to provide conditions suited to early successional invertebrate communities. Two techniques that may provide such conditions are disturbing the substratum using a mechanical excavator, and adding organic material such as barley straw.

Substratum composition and structure influences aquatic invertebrate community composition (reviewed by Minshall 1984). The substratum in the existing ponds at Mick's Lagoon consisted of a homogeneous expanse of very soft mud covered by a layer of fine silt, conditions that are unsuitable for many invertebrates (McLachlan and Cantrell 1976; Minshall 1984; Ryan 1991). In contrast, the substratum of newly created ponds was coarser, more spatially complex, less silty, and contained more particulate organic material (Chapter 8). These conditions are generally more favourable for aquatic invertebrates (Minshall 1984; Moss 1988) than conditions in the old ponds. I considered that disturbing the substratum in old ponds might provide a substratum similar to that of newly excavated ponds, and therefore one more suitable for early successional invertebrates. Lellák (1965) reported that the benthic fauna proliferated in Mansfeldova oxbow, a small lake near the River Elbe, after the substratum was disturbed.

Second, I considered that adding barley straw to ponds at Mick's Lagoon, may suit early successional invertebrate species by providing an abundance of coarse particulate organic material (CPOM) as is typical of many newly created wetlands (Nursall 1952; Patterson and Fernando

1969; McLachlan 1974; Danell and Sjöberg 1982; Murkin *et al.* 1982; Voshell and Simmons 1984; Fredrickson and Reid 1988; Murkin and Kadlec 1986; Reid 1985). Barely straw additions have been used successfully to increase invertebrate standing crop in gravel pits in England (Street 1983). I found similar results at some of the sites investigated in the pond experiments described in Chapter 8. Furthermore, my observations of invertebrates in ponds to which straw had been added suggested that nektonic invertebrates, at least, were most abundant where the straw had an open, buoyant structure, such as at the edge of patches of straw. They appeared least abundant in the middle of large clumps of straw. In an experimental comparison of several substrata, Street and Titmus (1982) also reported that invertebrates were most abundant in the most open, buoyant substrata. I hypothesized that invertebrate biomass and taxonomic composition at the edges of patches of straw would differ from that in 'open water', away from straw.

In this chapter, I investigate the effects of disturbing the substratum, and adding patches of barley straw to the substratum, on invertebrate biomass and community composition at Mick's Lagoon.

METHODS

During clearance of vegetation from the margins of Mick's Lagoon in early September 1994, most of the substratum at the margins (out to *c.* 15 m) of the existing wetland was disturbed by raking it back and forwards with the bucket of a Hitachi EX200 excavator (Fig. 9.1). The bucket was 2 m wide with *c.* 20 cm long teeth. Some areas of the substratum were left undisturbed to enable an investigation of the response of invertebrates to 'disturbed' and 'undisturbed' substrata.

In late September 1994, a layer of barley straw was added to the water over part of the undisturbed substratum and part of the disturbed substratum. As expected, the straw sank, after about one week, to form fairly discrete patches on the disturbed and undisturbed substrata. Thus, four experimental substrata were established; 'disturbed + straw', 'disturbed, no straw', 'undisturbed + straw' and 'undisturbed, no straw'. The experimental substrata were spatially interspersed. It therefore seemed reasonable to assume that any differences among experimental substrata could be attributed to those substrata, rather than to spurious effects such as underlying gradients in the old substratum.

Figure 9.1. Mick's Lagoon. The substratum in the foreground has just been disturbed using the excavator. The water is still turbid in this photograph, but it cleared within a few days. Note the island that was created as a potential roosting and nesting site for black stilts.

Seven samples of water and substratum were taken from each experimental substratum on 31 January 1995, four months after the barley straw was added. Each sample was taken from within a 0.1 m^2 stainless steel cylinder, using a 0.8 mm mesh sieve as described in Appendix 4. Edges of straw patches were sampled by placing the sampling cylinder so that the edge of the patch ran through the centre of the cylinder. Samples were taken in 15 - 20 cm deep water, preserved in 15 % formalin and transported back to the laboratory. Invertebrates were then removed, identified, counted, and separated into four food types; Oligochaeta, Chironomidae, nekton and hard-shelled invertebrates (see Chapter 8 for the rationale for, and definitions of, food types). Invertebrates were dried to constant mass at 60° C and weighed. The mass of hard-shelled invertebrates was corrected for shell and case mass, as described in Chapter 8.

Note that the timing of vegetation clearance at Mick's Lagoon meant that samples were taken two months later in this experiment (end of January) than in the experiment reported in Chapter 8

(November/December). Invertebrate biomass and community composition of samples taken during these two experiments must therefore be compared with caution.

Statistical analysis

The experiment was designed as a two-factor Model I ANOVA with 'substratum disturbance' and 'straw addition' as the factors. For each sample, six response variables were measured; biomass of Oligochaeta, Chironomidae, Nekton, and Hard-shelled invertebrates, total invertebrate biomass, and number of taxa. These six variables were analysed as separate ANOVAs because I was not interested in interactions between them. Homogeneity of sample variances was tested using Cochrane's C test (following Winer 1971 and Underwood 1981) and sample distributions were inspected graphically for deviations from normality. Where necessary, data were $\log_{10}$- or square root-transformed. Chironomid biomass data could not be transformed to meet the assumptions of parametric ANOVA and were therefore analysed using a Kruskal-Wallis non-parametric ANOVA.

Tukey's T-tests were used to compare means following statistically significant ($\alpha < 0.05$) parametric ANOVAs. Non-parametric Tukey-type comparisons (following Zar 1984, p. 199) were used to compare medians following statistically significant non-parametric ANOVAs. ANOVAs and Tukey's T-tests were performed using the statistical package Statistica (StatSoft Incorporated 1994).

RESULTS

Biomass

The addition of straw significantly affected all six response variables, while substratum disturbance significantly affected three variables: mean oligochaete biomass, mean total biomass, and mean taxonomic richness (Table 9.1). The interaction terms in the ANOVAs were significant for oligochaete and nektonic biomass, and taxonomic richness (Table 9.1). This indicates that the magnitude of the effect on these variables of adding straw depended on whether or not the substratum had been disturbed (and *vice versa*). Comparisons of means and medians are shown in Table 9.2.

Table 9.1. Summary of results of ANOVAs on biomass of four food types, total invertebrate biomass, and taxonomic richness (see text for details). DIST = disturbance, STRAW = straw addition. Values shown are F-ratios from parametric ANOVAs on all dependent variables except the values for chironomid biomass, which was analysed with a Kruskal-Wallis non-parametric ANOVA. For chironomid biomass, the Kruskal-Wallis test statistic, H, is shown. n.s. $P > 0.05$; * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$; **** $P < 0.0001$.

		Biomass					
Source of variation	d.f.	Log_{10} Oligochaete	Chironomidae (H)	√ Nekton	Hard-shelled invertebrates	Log_{10} Total	Taxonomic richness
DIST	1	15.40***	3.82 n.s.	2.07 n.s.	2.87 n.s.	13.48**	13.27*
STRAW	1	14.35***	5.50*	97.31****	24.43****	54.66****	60.92****
DIST × STRAW	1	4.94*	0.69 n.s.	20.62****	0.07 n.s.	0.07 n.s.	10.41**
Error	24						

Table 9.2. Comparisons of means and medians following significant ANOVAs (see Table 9.1 and text for details). Means were compared using Tukey's T-tests, and medians (of chironomid biomass) were compared using non-parametric Tukey-type tests (following Zar, 1984, p. 199). For each dependent variable, substrata that did not differ significantly ($P > 0.05$) are indicated by the same letter in the row for that variable.

	Substratum			
Dependent variable	Disturbed + straw	Undisturbed + straw	Disturbed no straw	Undisturbed no straw
Oligochaeta [a]	A	B	B	B
Chironomidae [b]	A	AB	AB	B
Nekton [c]	A	A	B	C
Hard-shelled invertebrates [d]	A	AB	BC	C
Total [a]	A	AB	B	C
Number of taxa [d]	A	A	B	C

[a] Log 10-transformed

[b] Kruskal-Wallis non-parametric ANOVA

[c] Square-root-transformed

[d] No transformation necessary

Oligochaeta comprised a large proportion of the mean biomass in samples taken from all experimental substrata (Fig. 9.2). Samples from the disturbed + straw substratum contained *c.* five times greater mean oligochaete biomass than samples from the other three experimental substrata. The significant interaction term suggests that substratum disturbance and straw addition act synergistically to increase oligochaete biomass.

Chironomidae were absent or scarce in all samples. Samples from the disturbed + straw substratum contained the greatest median chironomid biomass (0.05 $g.m^{-2}$), which was significantly greater than the median chironomid biomass in the undisturbed no straw substratum (0.0 $g.m^{-2}$). Median chironomid biomass in both the undisturbed + straw and disturbed no straw substrata was 0.01 $g.m^{-2}$, and did not differ significantly from any of the experimental substrata (Table 9.2).

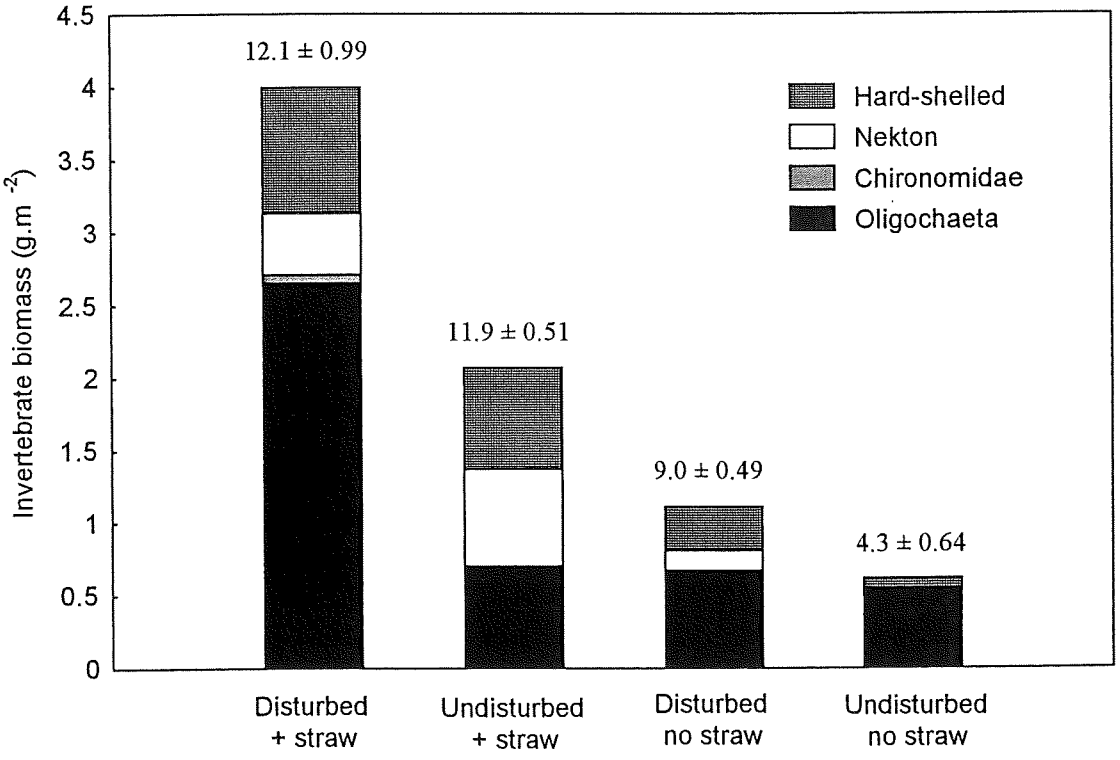


Figure 9.2. Mean (n = 7) biomass of four food types in samples taken from four substrata at Mick's Lagoon. Numbers above each column show mean (± SE) number of taxa in the seven samples taken from each substratum. Results of ANOVAs and comparisons of means and medians are shown in Tables 9.1 and 9.2. Raw data, means and standard errors of means are listed in Appendix 10.

Mean nektonic and hard shelled biomass were much greater on substrata that had received straw additions than in substrata that had not. These differences were highly significant (Table 9.1). In contrast, the biomass of these two food types did not differ between disturbed and undisturbed substrata. The interaction term in the ANOVA of nektonic biomass was highly significant. This interaction, together with inspection of Figure 9.2, suggests that nektonic biomass increases more where straw is added to an undisturbed substratum (at Mick's Lagoon) than where it is added to a disturbed substratum.

Total biomass was significantly greater on substrata that had received straw additions than in substrata that had not, and was also significantly greater on disturbed than undisturbed substrata.

The mean number of taxa found in samples differed dramatically and significantly among the experimental substrata (Fig. 9.2). Samples from both substrata that had received straw additions contained 12.0 taxa on average, whereas a mean of only 6.7 taxa were found in samples from the two substrata that had not received straw additions. Samples from disturbed substrata also contained significantly more taxa than samples from undisturbed substrata. The interaction term in the ANOVA of taxonomic richness was statistically significant. This interaction, and consideration of the mean taxonomic richness in each experimental substratum, suggests that taxonomic richness increases more where straw is added to an undisturbed substratum than where it is added to a disturbed substratum.

Community composition

Twenty three taxa were found in samples taken from the experimental substrata (Table 9.3). Oligochaete worms and the small (< 6 mm long) bivalve mollusc, *Sphaerium novaezelandiae*, occurred in all 28 samples (Appendix 10), and were the most abundant taxa in samples taken from all substrata. They were found at mean densities ± SE between 583 ± 129 and 5530 ± 1483 per m^2. The snail, *Physa acuta*, was also present at high densities in substrata to which straw had been added (704 ± 224 to 996 ± 96 per m^2) and the disturbed no straw substratum (100 ± 47 per m^2). However, *P. acuta* was found at a density of only 4.3 ± 3 per m^2 in the undisturbed no straw substratum.

As well as containing the most taxa, samples from 'straw substrata' contained higher numbers of most invertebrate taxa than samples from 'non-straw substrata' (Table 9.3). For example, the backswimmer, *Anisops* sp. and the waterboatman, *Sigara* sp. were significantly more abundant in

Table 9.3. Mean abundance of taxa, and mean taxonomic richness, in samples taken from Mick's Lagoon on 31 January 1995. Note that abundances are presented as number of individuals per 1 m^2, and taxonomic richness is presented as number of taxa per 0.1 m^2 sample. The total numbers of taxa found in the seven samples from each experimental substratum are also shown.

	Abundance							
	Disturbed + straw		Undisturbed + straw		Disturbed no straw		Undisturbed no straw	
Taxon	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Oligochaeta	5530	1483	2134	384	1384	148	1823	424
Sphaerium novaezelandiae	1620	579	1099	172	996	248	583	129
Physa acuta	996	96	704	224	100	47	4.3	3.0
Potamopyrgus antipodarum	21	17	2.9	1.8	330	218	1.4	1.4
Lymnaea tomentosa	119	53	74	16	44	20	19	10
Anisops sp.	101	28	126	35	10	5	7.1	5.7
Sigara sp.	56	16	126	19	16	5	1.4	1.4
Chironomus zealandicus	139	64	26	10	21	5	0	0
Berosus sp.	40	16	27	8	39	13	2.9	1.8
Tanypodinae	23	8	23	7	20	8	1.4	1.4
Gyraulus corinna	24	7	7	4	7.1	5.7	0	0
Xanthocnemis zealandica	11	6	20	8	0	0	0	0
Glossiphonia sp.	11	3	9	3	0	0	2.9	2.9
Hygraula nitens	5.7	5.7	2.9	1.8	2.9	1.8	0	0
Ceratopogonidae	2.9	1.8	2.9	2.9	0	0	2.9	1.8
Rhantus pulverosus	2.9	1.8	2.9	1.8	1.4	1.4	0	0
Liodessus sp.	2.9	1.8	0	0	1.4	1.4	0	0
Hydrachna maramauensis	1.4	1.4	2.9	1.8	0	0	0	0
Antiporus strigosulus	0	0	0	0	2.9	2.9	0	0
Microvelia macgregori	1.4	1.4	0	0	0	0	0	0
Oxyethira albiceps	0	0	1.4	1.4	0	0	0	0
Paroxyethira hendersoni	0	0	0	0	1.4	1.4	0	0
Hudsonema amabilis	0	0	0	0	1.4	1.4	0	0
Number of taxa	12.14	0.99	11.86	0.51	9	0.49	4.29	0.64
Pooled number of taxa	19		18		17		11	

straw than non-straw substrata, as were larvae of the damselfly, *Xanthocnemis zealandica*; the midge, *Chironomus zealandicus*; the leech, *Glossiphonia* sp. and the snail, *Lymnaea tomentosa* (two factor ANOVAs, $<0.0001 < P < 0.04$).

Taxa other than the above were usually present at mean densities less than 5 per m^2 (Table 9.3). Exceptions were the snails, *Potamopyrgus antipodarum* and *Gyraulus corinna*; the beetle, *Berosus* sp.; larvae in the midge subfamily Tanypodinae, and larvae of the moth *Hygraula nitens*.

DISCUSSION

Food supplies for black stilts in artificial or modified wetlands in the Upper Waitaki Basin appear to decline in abundance and suitability over time (Chapter 8). In this experiment I investigated two techniques for the enhancement of food supplies in a previously modified wetland, Mick's Lagoon. My results show that one of these techniques, adding straw to the substratum, could be used to provide an abundance of suitable black stilt food supplies. Biomasses of all four of the broad food types that I recognised were greater in substrata to which straw had been added than in substrata that had not received straw additions.

The other technique, disturbing the substratum with an excavator, appears less promising as a management technique than adding straw, at least at Mick's Lagoon. Only oligochaete biomass and (consequently) total biomass were significantly greater in disturbed substrata than undisturbed substrata.

In terms of total biomass, the disturbed + straw substratum appeared to provide the most potential food for black stilts. However, current knowledge of black stilt foraging behaviour (Pierce 1985, 1986b; this thesis, Chapters 3, 10, 11) suggests that the taxonomic composition of invertebrates in wetlands, as well as total invertebrate biomass, influences the value of foraging habitat to black stilts. Similar observations have been made regarding other birds (*e.g.* Britton 1983; Goss-Custard 1969, 1984; Goss-Custard *et al.* 1977; Fredrickson and Reid 1988; Eldridge 1990; Phillips 1991; Colwell and Landrum 1993). Thus, the disturbed + straw substratum may not necessarily be the best substratum from a black stilt's point of view. For example, Oligochaeta may be less available to black stilts, and therefore less valuable for a given biomass, than nektonic invertebrates. If so, the disturbed + straw substratum (which contained high oligochaete biomass) may be no more suitable that the undisturbed + straw substratum.

Unfortunately, we currently lack the detailed knowledge of black stilt foraging behaviour that would be necessary to confidently evaluate food supplies for black stilts. Management of wetlands for black stilts would benefit from a more detailed understanding of the role of invertebrate community composition in habitat selection by black stilts. Nevertheless, on the basis of current knowledge of black stilt foraging behaviour and habitat selection (Pierce 1982a, 1985, 1986b; this thesis Chapters 5, 10 and 11), I suggest that adding straw to either disturbed or undisturbed substrata will increase food supplies for black stilts at Mick's Lagoon.

In a study of invertebrate communities on barley straw and several other substrata in old gravel pits in England, Street and Titmus (1982) found that samples from a polypropylene twine substratum contained the most invertebrates. They speculated that this was because the twine provided a more open, buoyant substratum than the other substrata. In this study, I showed that invertebrate biomass was greater at the edges of patches of straw than in substrata that lacked straw. Because my experiment was conducted in shallow water, I was able to observe invertebrates in the patches of straw. My observations support the contention of Street and Titmus (1982); invertebrates appeared to be most abundant at the edges of patches of straw partly because such edges provided an open buoyant substratum on which snails and nektonic invertebrates could feed and 'sit'. Therefore, adding barley straw is likely to be most effective as an invertebrate enhancement technique when the amount of edge is maximised, a situation that could be accomplished by spreading the straw in a mosaic of many small patches.

CHAPTER 10

Prey consumption by black stilt chicks in captivity

INTRODUCTION

To maximize black stilt breeding success, enhanced wetlands need to provide both chicks and adults with abundant and suitable food supplies. In the wetland enhancement experiments reported in Chapters 7 - 9 I assessed the suitability of different invertebrate taxa as foods for adult black stilts. That assessment was based mainly on observations of the foraging behaviour of adult black stilts at sites where invertebrate community composition had been measured or described (Pierce 1982a, 1985, 1986b; this thesis, Chapters 3, 5, 6, and 11). However, no detailed observations of the behaviour of black stilt chicks foraging in the wild have been recorded, and very little is known about their ability to capture and consume different aquatic invertebrate taxa. Consequently, it is difficult to assess the suitability of food supplies in enhanced wetlands for black stilt chicks.

A few common and abundant taxa (referred to as 'species', henceforth) dominated aquatic invertebrate biomass on many of the experimental substrata investigated in Chapters 7 - 9. An opportunity to investigate the suitability of these species as food for black stilt chicks was provided by the black stilt captive breeding programme at Twizel. In this chapter, I report the results of an experiment designed to test four hypotheses:

1. That black stilt chicks capture and consume different prey taxa at different rates.
2. That the rate of prey consumption by black stilt chicks varies with chick age.
3. That some prey species are more 'attractive' to black stilt chicks than others prey species (see Methods for a definition of 'attractiveness').
4. That the attractiveness of different prey species to black stilt chicks varies with chick age.

During the experiment I was able to observe the feeding behaviour of black stilt chicks in detail. I also present descriptions of that behaviour in this chapter.

METHODS

Aviary routine

Black stilt chicks are raised at the Department of Conservation's captive rearing facility in Twizel from eggs collected from black stilt nests in the wild. Immediately after chicks hatch, they are placed in 1.2 m × 1.2 m brooders under a controlled temperature and light regime (see Reed (1994b) for details). A one-way window enables chicks to be observed without disturbing them. Chicks older than *c.* 7 days have daytime access to a small (1.8 × 4 m) outdoor aviary. After chicks have fledged (at 39 - 55 days of age), they are transferred to large (98 - 196 m^2) outdoor aviaries.

Newly hatched chicks have continuous access to a tray of aquatic invertebrates, which are collected from streams and ponds near the aviaries. They also have continuous access to a tray of minced ox heart mixed with live 'mealworms' (*Tenebrio molitor* larvae). The tray of aquatic invertebrates typically includes many or all of the prey species investigated in this experiment. Fresh invertebrates are provided four to five times each day and fresh ox heart mix is provided as required. Once chicks are feeding well on the ox heart mix (3 - 10 days) they are no longer fed aquatic invertebrates.

Experimental procedure

Each brooder housed a 'brood' of four uniquely colour-banded chicks, of similar age, but not necessarily of the same parentage. The brood was defined as the experimental unit (*i.e.* 'replicate') in the experiment described below. The experiment consisted of five feeding 'trials'; two on broods of chicks aged 2 - 3 days and one on broods of chicks aged 6 - 7 days, 21 - 22 days and 26 - 30 days. One brood was used twice, at 2 - 3 and 6 - 7 days of age.

In each feeding trial, the brood of chicks was presented with 30 individuals of 11 prey species (see below), one species at a time, at 30 minute intervals. Each prey presentation lasted for five minutes. Thus, every 30 minutes, 30 individuals of each prey species were presented to the brood of chicks, for five minutes. (Note, however, that the first trial (on 2-3 day old chicks) differed slightly from the above routine; only ten prey species were presented because fewer than 30 individuals of one of the prey species (*Physa acuta*) could be found that day.) Prey were presented on a standard substratum, and in random order, with the constraint that any given prey species

could be presented first to only one brood. This constraint was imposed to minimise any possible bias associated with the first presentation. Timing of each five minute presentation began as soon as any chick was within one body length of the plate, which was almost always within 10 seconds. The trays of aquatic invertebrates and ox heart mix that were normally in the brooder were removed during prey presentations.

The 11 'prey species' consisted of nine of the most abundant taxa in the substratum manipulation experiments (Chapter 7 - 9), and two 'controls'. The controls were 1) sticks similar in size to the prey species, (8 - 13 mm long), and 2) larvae of *Triplectides* sp., a caddisfly that uses small sticks as its case. Sticks were included in the trial to test whether chicks would peck at inanimate insect-sized objects. *Triplectides* sp. was included to test whether black stilt chicks would peck at a highly cryptic prey species. The other prey species comprised oligochaete worms, two snail species and six insect species. The snails were *Physa acuta* and *Lymnaea tomentosa*. The insects were the waterboatman, *Sigara* sp., and larvae of the damselfly, *Xanthocnemis zealandica*; the midge, *Chironomus zealandicus*; the mayfly, *Deleatidium* sp.; and the caddisflies *Aoteapsyche colonica* and *Hudsonema amabilis* (see Appendix 7 for details of taxonomic classifications). Within each prey species, individuals presented to the chicks were similar in length. Among species (excluding oligochaete worms, which change length as they move) typical prey size ranged from 7 mm high (*P. acuta*) to 15 mm long (*Triplectides* sp., including case).

To minimise variation in the hunger of chicks in the experiment, all feeding trials began at least one hour after chicks had first been fed in the morning. The substratum on which prey were presented consisted of 190 g stones (1 - 35 mm long), four leaves (40 - 76 mm long, 15 mm wide) and four sticks (58 - 81 mm long), which were spread evenly on a 23 cm diameter plastic plate and covered with 1.5 cm deep water. Prey were distributed evenly on the substratum at least one minute before each presentation to allow the prey to find cover. The density of prey presented to chicks (790 m^{-2}) was within the range of prey densities found in the small-scale substratum addition experiment (0 - 3500 m^{-2}; Table 7.4).

After each prey presentation, the number of prey consumed was calculated from the number that remained. When empty snail shells or caddisfly cases remained, the occupant was considered to have been consumed (unless a shell-less or case-less individual also remained). Calculations of the number of oligochaete worms consumed were approximate because those that remained were sometimes broken into small fragments.

I assessed the 'attractiveness' of different prey species to black stilt chicks in two ways. First, I estimated the proportion of time that chicks spent feeding on each prey species during the five minute prey presentations. Second, I recorded qualitative descriptions of the rates at which chicks pecked at each prey species. To estimate proportion of time spent feeding I recorded, every 10 seconds, whether each chick was 'present' at the feeding plate. A chick was considered to be present if it was within one body length of the plate.

During the feeding trials I also made notes on the ability of chicks of different ages to capture, manipulate and consume different prey.

Statistical analysis

Friedman's two-factor non-parametric ANOVAs were used to test whether the median number of prey consumed, and/or the median proportion of time spent feeding, varied among prey species and/or among different aged broods. Because the brood was the experimental unit in these experiments, the data used in these analyses were: 1) the numbers of prey consumed, and 2) the mean percentages of time that broods spent feeding during the five minute prey presentations. For the purpose of these analyses, the two missing data for *P. acuta* in the first trial on 2-3 day old chicks were estimated from the corresponding data for *P. acuta* from the second trial on 2-3 day old chicks.

Spearman's rank correlation was used to test whether the number of each prey species consumed, and/or the proportion of time spent feeding on each prey species, was correlated with chick age. The power of these tests was low because each prey species was presented to only five broods. Nevertheless, the rank correlation coefficients at least indicate the direction and strength of correlations.

Rank correlation was also used to test whether order of presentation affected the number of prey consumed, and/or the proportion of time spent feeding in each trial.

RESULTS

The median number of prey consumed by black stilt chicks varied among prey species (Friedman test statistic, $\chi^2_r = 41.8$, d.f. = 10, $P < 0.0001$; Table 10.1). It also varied among chicks of different ages ($\chi^2_r = 28.3$, d.f. = 4, $P < 0.0001$). Number of prey consumed was not correlated with order of presentation (Spearman's rank correlation, $-0.02 < r_s < 0.45$, n = 11, $P > 0.05$ for all trials).

All 30 *Sigara* sp. were consumed by chicks of all ages. The fast movements of *Sigara* sp. appeared to excite chicks, which chased and pecked rapidly at this prey species. Two to three day old chicks dropped *Sigara* sp. more often than older chicks, which consumed most *Sigara* sp. within two to three minutes.

Table 10.1. Number of prey eaten by black stilt chicks of different ages. Thirty individuals of each prey type were presented to broods of four black stilt chicks, for five minutes. Prey types were presented in random order, at 30 minute intervals, on a standard substratum (see text for details.) Spearman's rank coefficients of correlation (r_s) between number of prey consumed and chick age are also shown. * $P < 0.05$ (note that for a two-tailed test, the critical value of $r_{s\ (\alpha = 0.05,\ n = 5)} = 1.0$)

	Chick age						
Prey 'species'	2-3 d [a]	2-3 d	6-7 d [a]	21-22 d	26-30 d	mean	r_s
Sigara sp.	30	30	30	30	30	30.0	-
Xanthocnemis zealandica	20	27	29	30	30	27.2	0.95
Chironomus zealandicus	28	18	23	30	30	25.8	0.65
Deleatidium sp.	25	27	19	28	29	25.6	0.67
Aoteapsyche colonica	12	25	28	28	28	24.2	0.86
Oligochaeta	16	25	28	21	26	23.2	0.41
Physa acuta	-	5	19	24	29	19.3	1.0
Lymnaea tomentosa	2	4	7	12	26	10.2	0.98
Hudsonema amabilis	4	7	6	30	28	15.0	0.72
Triplectides sp.	0	0	3	7	11	4.2	1.0*
Sticks	0	0	0	1	2	0.6	0.92
Mean	13.7	15.3	17.5	21.9	24.5	18.7	

[a] These two trials were conducted on the same brood.

Chicks of all ages also pecked rapidly at *Xanthocnemis zealandica*, *Chironomus zealandicus*, *Deleatidium* sp. and *Aoteapsyche colonica*, and most individuals of these prey species were eaten in most trials (Table 10.1). Larvae of *X. zealandica* struggled vigorously when captured, and were sometimes able to escape from 2 - 3 day old chicks, by 'flicking' their abdomens while the chicks were manipulating them in their bills. *Deleatidium* sp. and *A. colonica* struggled when captured, but not as vigorously as *X. zealandica.* Oligochaete worms elicited slower peck rates than the above prey species, but most individuals of this taxon were also consumed in most trials.

The number of prey consumed tended to increase with chick age for all prey types (except *Sigara* sp.). However, this increase was greatest in trials involving five prey types that were consumed in only low numbers by young chicks. These prey types were the two snail species (*Physa acuta* and *Lymnaea tomentosa*), the two cased caddisfly species (*Hudsonema amabilis* and *Triplectides* sp.), and the sticks (Table 10.1). The coefficients of rank correlation between chick age and number of prey consumed for these items were all were high and positive, but only that of *Triplectides* sp. ($r_s = 1.0$, $P < 0.05$) was statistically significant.

Although 2 - 3 day old chicks frequently pecked at both snail species, the snails' smooth, hard shells usually slipped out of the chicks' bills, and only 16 of 120 snails presented to chicks of this age were consumed (Table 10.1). In contrast, chicks older than 2 - 3 days, particularly 26 - 30 day old chicks, were better able to capture, manipulate and consume snails (including shells).

Both caddisfly species were easily captured by chicks of all ages. However, few *Triplectides* sp. were consumed, and high numbers of *H. amabilis* were consumed only by 21 - 22 and 26 - 30 day old chicks (30 and 28 individuals consumed, respectively). Chicks usually dropped caddisfly larvae after picking them up and manipulating them in their bills. However, chicks older than 21 days usually consumed individuals of *H. amabilis*. When feeding on cased caddisflies, chicks tended to peck at moving larvae more frequently than at stationary larvae. They also tended to peck at the legs and heads of the larvae, if visible.

Although the sticks were frequently pecked at and picked up by chicks, only three disappeared in trials with chicks older than 21 days. It is likely that these were lost in the brooder, rather than eaten, as sticks were frequently dropped away from the plate by old chicks.

The efficiency with which chicks captured and manipulated prey increased dramatically with age. Two to three day old chicks took longer than older chicks to capture prey, and spent more time

manipulating prey in their bills before swallowing. They also frequently dropped prey, whereas 6 - 7 day old chicks rarely dropped prey. Chicks older than 21 days captured and swallowed prey efficiently and quickly.

On average, chicks in most broods spent most of their time at the feeding plate during prey presentations (Table 10.2; median = 74 %, interquartile range 67 - 85 %). The percentage of time that black stilt chicks spent feeding did not differ significantly among prey species (χ^2_r = 13.37, d.f. = 10, P = 0.20). Neither did it differ significantly among broods of different ages (χ^2_r = 8.65, d.f. = 4, P = 0.07). For no prey species was the percentage of time that black stilt chicks spent feeding significantly correlated with chick age ($-0.80 < r_s < 0.87$; Table 10.2).

Table 10.2. Percentage of time that different aged chicks spent at the feeding plate when presented with 30 individuals of each of 11 prey types, for five minutes. Each value is the mean percentage of time spent at a feeding plate by a brood of four chicks (see text for details). Spearman's rank coefficients of correlation (r_s) between percentage of time spent feeding and chick age are also shown. None were statistically significant (note that for a two-tailed test, the critical value of $r_{s\ (\alpha = 0.05,\ n = 5)} = 1.0$)

	Chick age						
Prey 'species'	2-3 d [a]	2-3 d	6-7 d [a]	21-22 d	26-30 d	mean	r_s
Sigara sp.	69	67	75	80	76	73	0.87
Xanthocnemis zealandica	73	58	94	61	89	75	0.41
Chironomus zealandicus	92	65	84	71	85	79	0.08
Deleatidium sp.	73	98	65	69	72	75	-0.56
Aoteapsyche colonica	85	88	86	27	82	74	-0.72
Oligochaeta	73	55	72	90	90	76	0.79
Physa acuta	-	86	85	74	79	81	-0.80
Lymnaea tomentosa	86	69	90	74	69	78	-0.24
Hudsonema amabilis	81	35	72	66	87	68	0.46
Triplectides sp.	77	62	82	68	96	77	0.62
Sticks	60	34	78	53	54	56	0.05
Mean	77	65	80	67	80	74	

[a] These two trials were conducted on the same brood.

Order of prey presentation was correlated with the percentage of time that black stilt chicks spent feeding in a trial conducted on 2 - 3 day old chicks ($r_s = 0.65$, n = 11, $P = 0.03$), but not in the other four trials. I ignored this correlation because none of the other nine tests for an order effect were statistically significant, and it is likely that this was a spurious correlation (as expected in one in twenty tests, when significance is taken at $P < 0.05$).

A distinct swallowing action by a stilt (*i.e.* a member of the genus *Himantopus*) has often been interpreted as the ingestion of a prey item (*e.g.* Burger 1980; Pierce 1982a, 1985, 1986b; Espin *et al.* 1983; Tinarelli 1987; but see Cullen 1994). The occurrence of a distinct swallowing action is invariably assessed from a distance, through binoculars or a telescope. During the experiment reported here, I often observed black stilt chicks consume prey with little or no swallowing action. This was true even for 26 - 30 day old chicks, which are almost the same size as adult black stilts. My observations were made from *c.* 50 cm.

DISCUSSION

Measurements of the biomass and abundance of aquatic invertebrates provide convenient, but approximate, indications of the value of foraging habitats for wetland birds. Many authors (*e.g.* Britton 1983; Goss-Custard 1969, 1984; Goss-Custard *et al.* 1977; Fredrickson and Reid 1988; Eldridge 1990; Phillips 1991; Colwell and Landrum 1993) consider that the value of foraging habitat to wetland birds is also influenced by aquatic invertebrate community composition. However, I know of no studies that have attempted to evaluate different aquatic invertebrate species as food for wetland birds. My study provides a basis, albeit limited, on which to assess the value of common invertebrate prey for black stilt chicks. Different invertebrate species were consumed in markedly different numbers by black stilt chicks, particularly by those younger than 7 days. The variation in the number of prey consumed, and variation in the ease with which they were captured and manipulated, suggests that in nature some prey species may be more accessible, and therefore more valuable, to black stilts chicks than other prey species.

The low numbers of snails (*Physa acuta* and *Lymnaea tomentosa*) and cased caddisflies (*Hudsonema amabilis* and *Triplectides* sp.) consumed by chicks younger than 7 days accounted for most of the variation in the number of prey consumed. Young chicks consumed few snails because they had difficulty picking up and manipulating the smooth shells. Cased caddisflies were easily captured and manipulated, but often appeared to be dropped intentionally by young chicks.

It seems likely that black stilt chicks in the wild would experience similar difficulties consuming these, and other, species of snails and cased caddisflies.

In contrast, chicks of all ages were easily able to capture, manipulate and consume invertebrates that lacked a shell or hard case (although the efficiency with which they did so increased with chick age). However, some of these prey species may be less easily captured in nature than they were in this experiment. Specifically, *Sigara* sp. and *Deleatidium* sp. may be better able to escape because they are highly motile, and oligochaete worms may be less vulnerable because they burrow out of sight within the substratum. Nevertheless, it seems likely that, in nature, these species would still be more easily captured and consumed than snails or caddisfly larvae.

Although *Aoteapsyche colonica* was easily captured and consumed in this experiment, in nature this species inhabits shelters constructed from stones and plant fragments and silk (Cowley 1978). These shelters would camouflage the larvae, and reduce their movement (perhaps substantially). Consequently, larvae of *A. colonica* in nature are probably less prone to capture by black stilts that they were in this experiment.

The remaining two prey species, *Chironomus zealandicus* and *Xanthocnemis zealandica*, are likely to be easily captured and consumed in the wild, as they were in this experiment. Larvae of *C. zealandicus* burrow through the substratum, but their bright red bodies are often partly visible at the surface of mud. Their visibility, relatively large size, and lack of hard body suggest they are a highly suitable prey for black stilt chicks. Furthermore, my field observations indicate that *C. zealandicus* is a highly attractive prey species to adult black stilts. For example, black stilts on lake deltas congregated in areas where *C. zealandicus* was abundant and pecked at high rates. *X. zealandica* should also provide highly suitable food for black stilt chicks because it too is a large, slow, easily visible species.

Variation in the number of prey consumed in this experiment appeared to be mainly a result of variation in prey morphology. In natural wetlands, the number of prey consumed by black stilt chicks will also be influenced by factors such as substratum, water turbidity and velocity, weather, light conditions (Pierce 1985, 1986b), and presumably chick experience. Furthermore, for a given biomass the nutritional value of different prey species varies (Driver *et al.* 1974; Driver 1981). Nevertheless, the results of this experiment contribute to our limited understanding of the relative value of different prey species to black stilts, and have implications for the evaluation of food enhancement techniques.

Therefore, on the basis of this experiment and my observations of black stilts and aquatic invertebrates in nature, I propose the following tentative ranking of the value of different prey taxa to black stilt chicks. For a given biomass, (excluding shells and cases) *X. zealandica* and *C. zealandicus* should be considered the most valuable prey species for black stilt chicks of all ages, followed by *Sigara* sp. and *Deleatidium* sp., then by oligochaete worms. The snails *P. acuta* and *L. tomentosa*, and the cased caddisfly *H. amabilis* should be considered less valuable than the above taxa, particularly for chicks younger than 21 days. The value of the larvae of *A. colonica* as food for black stilts cannot be assessed because the extent to which their shelters protect them from capture is unknown.

In the absence of more detailed information I suggest that other invertebrate species should be evaluated as prey for black stilt chicks on the basis of their similarity in morphology, crypsis and motility to the above species. For example, other damselfly and chironomid species may be similar in value to *X. zealandica* and *C. zealandicus*, respectively; nektonic invertebrates such as larval and adult diving beetles (Coleoptera: Dytiscidae) and backswimmers (Hemiptera: *Anisops* sp.) are probably similar in value to *Sigara* sp., and small gastropod molluscs such as *Potamopyrgus antipodarum* are probably similar in value to *P. acuta* and *L. tomentosa*. Future research could profitably investigate the extent to which invertebrate community composition in wetlands influences foraging behaviour, growth, and ultimately survival, of black stilt chicks.

During this experiment I observed that black stilt chicks presented with sticks spent 34 - 78 % of their time pecking at them. Admittedly, black stilts were probably conditioned to expect trays to contain food. Nevertheless, the readiness with which black stilts pecked at inanimate objects suggests that peck rates may not necessarily provide a good indication of prey density in nature.

I also observed that black stilt chicks were able to consume prey with little or no apparent swallowing action. In a field study of the foraging behaviour of black-necked stilts (*Himantopus mexicanus*), Cullen (1994) also observed prey captures (of waterboatmen) that were not accompanied by distinct swallowing motions. My observations, and those of Cullen, emphasize that indices of pecking success based on the proportion of swallows observed (*e.g.* Burger 1980; Pierce 1982a, 1985, 1986b; Espin *et al.* 1983; Tinarelli 1987) should be interpreted with caution.

CHAPTER 11

Use of experimental ponds and enhanced wetlands by stilts

INTRODUCTION

To maximize the chances of black stilts breeding successfully in managed wetlands, such wetlands first need to attract black stilts. Large scale wetland enhancement projects - currently under way - will provide the ultimate test as to whether black stilts will breed in managed wetlands in the Upper Waitaki Basin. Already, both black and pied stilts have been sighted foraging at two recently enlarged wetlands, Mick's Lagoon and Aviary Wetland (see Chapter 8 for site descriptions and maps). In addition, black and pied stilts have been sighted foraging and/or nesting at five of the six sites at which experimental ponds were constructed (Chapter 8). These sightings are encouraging for wetland managers because they demonstrate that artificial or modified wetlands can provide suitable stilt habitat. The first objective of this chapter is to provide a formal record of sightings of black and pied stilts at experimental ponds and recently enhanced wetlands.

The rationale for the experiments reported in Chapters 7 - 9 includes an assumption that the type and amount of aquatic invertebrates in wetlands can influence habitat selection by black stilts. This assumption has not been formally tested, although it is supported by field observations of black stilts (Pierce 1982a, 1985, 1986a; Chapter 5, this thesis). It is also supported by numerous studies that have demonstrated that the distribution and abundance of birds corresponds to that of their prey (for reviews see Chapter 9 in Hale 1980; Puttick 1984; Goss-Custard 1984, and Cody 1985). An opportunity to test whether food supplies can influence habitat selection by stilts, at least over tens of metres, arose when stilts used the experimental ponds at one of the sites investigated in Chapter 8, Ben Ohau Seepages.

Ponds were constructed at Ben Ohau Seepages in September 1993, and during the 1993/1994 breeding season black and pied stilts foraged in, and nested among, these ponds. Food supplies in the ponds were sampled on 8 - 9 December 1993, and analysed in terms of the biomass of four broad food types, Oligochaeta, Chironomidae, nekton, and hard-shelled invertebrates (see Chapter 8 for food type definitions). Thus, it was possible to relate habitat use by pied and black stilts to the biomass of these four broad food types. I included pied stilts because, in the absence of

large samples of black stilts, pied stilts provide a good surrogate species. For example, pied and black stilts forage and nest at similar sites (Robertson *et al.* 1983, Pierce 1982a, 1985, 1986a).

The use by stilts of experimental ponds at Ben Ohau Seepages also provided an opportunity to test whether stilt habitat selection was affected by the various experimental substrata. In particular, I was interested to see whether stilts at Ben Ohau Seepages had difficulty foraging in ponds to which barley straw had been added. They apparently did at Kevin's Diversion, one of the other experimental sites (Lynn Adams, pers. comm.). Thus, the third objective of this study was to test whether stilts spent the same amount of time foraging in different substrata at Ben Ohau Seepages.

METHODS

Records of sightings

I compiled records of pied and black stilt sightings at recently manipulated wetlands. These records were kept by myself and other experienced observers (Department of Conservation staff and Lynn Adams, an M.Sc. student at Canterbury University; see Adams 1995).

Pied stilt foraging at Ben Ohau Seepages

I determined the use of ponds by pied stilts on 20 December 1993. Black stilt use of ponds could not be measured because they were absent on that date. I used the following pre-determined protocol.

Pied stilts were observed for 3 hours (1042 - 1342 h) through a 25 × telescope from a terrace above the ponds. Figure 11.1 shows the ponds as seen from the terrace. After my arrival the stilts initially gave some alarm calls but did not fly. To reduce the chance of recording behaviour that may have been influenced by my arrival, I did not begin my observations until 15 minutes after arriving at the observation point. The stilts appeared to behave normally during the period that I observed them.

I repeatedly scanned, in a standard manner, fifteen recently excavated ('new') ponds, and an area of flooded grass adjacent to the ponds. I included the flooded grass because it was contiguous with the habitat provided by the experimental ponds, and I had previously noticed stilts foraging there. I

Figure 11.1. View of the ponds at Ben Ohau Seepages from the observation point. The flooded grass is immediately behind the most distant ponds.

did not measure stilt use of the existing wetlands ('old ponds') at Ben Ohau Seepages because these 'ponds' differed in size and shape, and were separated, from the new ponds.

All scans commenced at the closest pond and followed the same 'line'. I commenced each scan immediately after completing the previous scan. I made 30 scans, which took 6.2 minutes each on average. During each scan, for each pond, I recorded the first observed behaviour of any stilts that were present in or near the pond. Stilt behaviours are defined in Appendix 2. Stilts that were near (within 5 m of), but not in ponds were assigned to the nearest pond. I ignored stilts that were more than 5 m from the ponds (*e.g.* in the old wetland). Stilts that were equidistant from two ponds were recorded as such, but were excluded from the statistical analysis.

Statistical analyses

The data obtained from scans of the ponds cannot be assumed to be independent because the same few stilts were observed repeatedly, over a short period. Ideally, the relationship between the use of ponds by stilts and food supplies would be investigated in a properly replicated experiment, but

such an experiment was beyond the scope of this thesis. Nevertheless, the present study provides a much needed indication of the role of food supply in habitat selection by stilts in enhanced wetlands. Rather than discard this information, I present my analyses of the data, but emphasize that the reliability of the results is unknown because the data are not entirely independent.

I used Poisson regression to relate pied stilt foraging site selection to food supply at Ben Ohau Seepages. The response variable was the number of times pied stilts were sighted foraging in each pond, during the three hour observation period. The predictor variables were biomasses of three of the four food types defined in Chapter 8: Oligochaeta, Chironomidae and nekton. Hard-shelled invertebrate biomass was not used in the analysis because it was nil in 10 of the 15 ponds, and close to nil in the other ponds. See Chapter 8 for details of the measurement of invertebrate biomass at Ben Ohau Seepages.

I tested whether use of ponds by pied stilts was related to substratum with a χ^2 test of independence. The substrata were: 1) excavated, 2) excavated + barley straw, 3) excavated + stones, and 4) flooded grass. The observed frequencies for the three experimental substrata were obtained by pooling observations from all five ponds. Each observation of each pond was categorized according to whether pied stilts were: 1) present and foraging in the pond, 2) present in or near the pond but not foraging, and 3) absent.

RESULTS

Records of sightings

Pied and/or black stilts are known to have used at least five of the six wetlands at which substratum manipulations were undertaken. These included the experimental ponds at Mick's Lagoon, Aviary Wetland, Kevin's Diversion, the Tekapo Delta and Ben Ohau Seepages (see Chapter 8 for site details). Whether stilts used ponds at the sixth site, Irishman Ponds, is unknown. Stilts also foraged at Mick's Lagoon and Aviary Wetland in wetlands that had been enlarged and constructed in September 1994 and 1995, respectively. A summary of descriptive records of pied and black stilts use of these sites is presented in Table 11.1. Note that at least nine stilts used the ponds at Ben Ohau Seepages (at any one time) in the 1993/1994 breeding season, but fewer than nine (precise data are unavailable) used the ponds in the 1994/1995 season.

Table 11.1. Use of experimentally manipulated sites by pied and black stilts. The term 'node' refers to the plumage of hybrid stilts, which have been categorized on a scale that ranges from node A (pure pied stilt plumage) to node J (entirely black plumage; see Pierce 1984b for details).

Location	Date	Comments
Ben Ohau Seepages	November 1993	• Black and pied stilts were often seen foraging in the experimental ponds.
	"	• A black (Y/R-R) × pied pair nested and fledged at least one chick.
	"	• A node G (W/B-G) × node D-E pair nested. Their eggs were dummied. All eggs hatched but the chicks apparently did not survive.
	"	• A node F × pied pair nested and hatched chicks.
	20 December 1993	• The foraging behaviour of pied stilts was measured (the present study).
	18 February 1994	• One pied stilt and one node E and three juveniles were seen foraging in straw ponds. One pied stilt was roosting away from the ponds and one pied stilt was foraging in the outflow from the experimental ponds.
	1994/1995 breeding season	• One black × pied pair nested at Ben Ohau Seepages but the nest was either lost or abandoned.
Kevin's Diversion	1994/1995 breeding season	• Black stilt juveniles (*c.* eight months old) that had been released from the DOC aviary were often seen foraging at Kevin's Diversion.
	"	• At least one pair of pied stilts nested.
Aviary Wetland	1994/1995 breeding season	• One pair of pied stilts nested and fledged at least one chick.
	1995/1996 breeding season	• Newly constructed large (> 100 m long) ponds were used extensively by released juveniles. They were often seen foraging in the old stream, the level of which had been lowered. They began using ponds immediately after being released, while construction was still under way.
Tekapo Delta	1993/1994 breeding season	• Black and pied stilts foraged in experimental ponds.
Mick's Lagoon	11 May 1995	• Six black stilts were seen foraging in recently (September 1994) excavated habitat, and among flooded vegetation.

Pied stilt foraging at Ben Ohau Seepages

Pied stilts foraged in 11 of the fifteen ponds and in the flooded grass during the observation period. During any one scan, 0 - 5 pied stilts were observed foraging in, or present at, ponds or the flooded grass. Stilts that were present but not foraging were roosting, sitting, standing, or preening. Of the 480 observations of ponds (30 scans × 15 ponds and the flooded grass), pied stilts were observed foraging 42 times, were present but not foraging 43 times, and were absent 395 times (Table 11.2).

Invertebrate biomass in the ponds at Ben Ohau Seepages was dominated by larval Chironomidae (almost exclusively *Chironomus zealandicus*) in December 1993 (Fig. 11.2). Samples from ponds at Ben Ohau Seepages to which barley straw had been added contained the highest mean chironomid biomass of all experimental substrata, at all sites investigated in the pond experiment (Chapter 8). Samples to which stones had been added contained the least chironomid biomass at Ben Ohau Seepages (excluding old ponds, which were not investigated in the present study). Excavated ponds that received no substratum additions contained a mean chironomid biomass intermediate between that of 'straw' and 'stone' ponds. The pattern was similar, but less marked, for oligochaete and nektonic biomass (refer to Chapter 8 for full details). Food supplies were not measured in the flooded grass.

Chironomid biomass was the best predictor of the number of times pied stilts were sighted foraging in ponds; it explained 31 % of the deviance (Table 11.3). Oligochaete and nektonic biomass also explained significant, but smaller, proportions of the deviance (23.4 % and 19.3 % respectively). However, which of these variables was most likely to have influenced habitat use by pied stilts ponds cannot be reliably identified because the three predictor variables were highly intercorrelated ($0.73 < r < 0.85$, d.f. = 13, $0.005 < P < 0.0001$). I therefore present results of the regression for all three predictor variables (Table 11.3). Adding a second predictor variable (oligochaete or nektonic biomass) to the best (constant + chironomid biomass) model did not significantly reduce the deviance.

The behaviour of stilts in or near ponds was strongly associated with substratum ($\chi^2 = 84.72$. $P < 0.00001$; Table 11.4). χ^2 tests of individual cells in Table 11.4 show that pied stilts fed in, and were present at, ponds to which barley straw had been added significantly more often than expected. In contrast, they fed in, and were present at, ponds to which stones had been added less

Table 11.2. Behaviour of pied stilts at Ben Ohau Seepages on 20 December 1993. FOR= foraging; STA = standing; SIT = sitting; ROO = roosting; PRE = preening (see Appendix 8 for definitions of behaviours). Substrata are indicated as follows. E = excavated, EBS = excavated + barley straw, ES = excavated + stones, GRASS = flooded grass. The left hand column lists the time that each scan began, and each row represents a complete scan of the pond complex. Each cell represents a single observation of a pond or the flooded grass area. Within cells, each three letter code represents a pied stilt. For example, at 1330 h, three pied stilts were foraging in the flooded grass. The bottom three rows show the total numbers of observations of pied stilts foraging in (FOR), present at but not foraging in (OTH), and absent from (ABS), each pond. Pied stilts that could not be assigned to a pond because they were present on the narrow spits between two ponds are listed under compound pond numbers (*e.g.* 8/9). Note that those observations were excluded from the χ^2 test of independence.

Sub:	ES	ES	ES	EBS	ES	EBS	ES	E		EBS		E	EBS		E		EBS	E	E	GRASS
Pond:	1	2	3	4	5	6	7	8	8/9	9	9/10	10	11	11/12	12	12/13	13	14	15	
1042										STA				ROO				STA	STA	
1050										SIT		FOR					STA		STA	
1054										PRE						PRE				STA
1057			FOR					PRE		ROO		FOR								
1100								ROO		STA			FOR							
1108								ROO		ROO			FOR							
1110								ROO		ROO							FOR			
1118								ROO		ROO					FOR		FOR			
1125				FOR				PRE		ROO										
1132								SIT		STA							FOR			
1135													FOR							
1143									ROO											STA
1148									STA				FOR							
1155																				
1201									ROO											ROO ROO
1205									ROO											STA
1210									SIT											
1223		FOR								SIT										STA
1229		FOR	FOR							SIT										STA
1234										SIT ROO							FOR			
1242										ROO ROO							FOR			
1246										SIT SIT							FOR			SIT FOR
1300										SIT		FOR							FOR	
1314										FOR		FOR					FOR			FOR STA
1318			FOR			PRE				FOR										STA ROO
1325				FOR		FOR				FOR			FOR							STA
1330										FOR			FOR							FOR FOR FOR
1334										FOR			FOR							
1338								FOR					FOR							
1342											ROO		FOR				FOR			
FOR	0	2	3	2	0	1	0	1	(0)	5	(0)	4	9	0	1	(0)	8	0	1	5
OTH	0	0	0	0	0	1	0	7	(5)	19	(1)	0	0	1	0	(1)	1	1	2	12
ABS	30	28	27	28	30	28	30	22	(25)	6	(29)	26	21	29	29	(29)	21	29	27	13

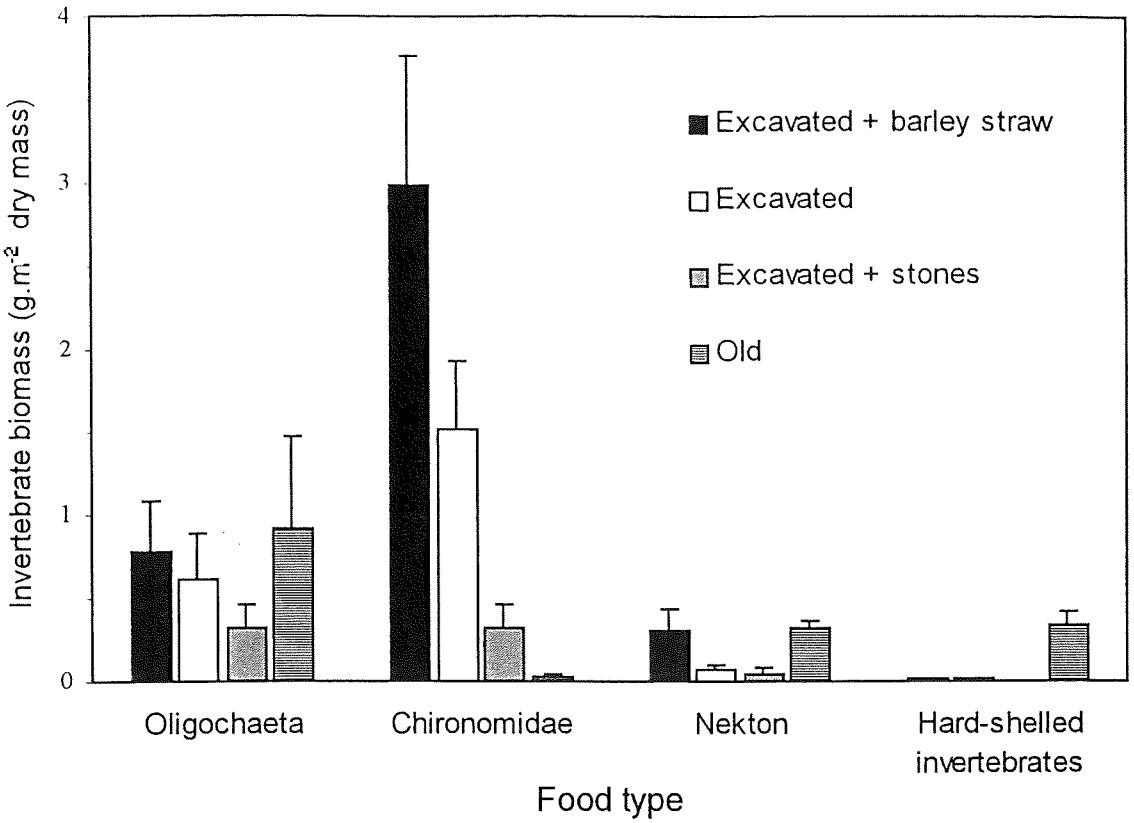


Figure 11.2. Mean (+ SE) invertebrate biomass in samples taken from four experimental substrata at Ben Ohau Seepages on 8 - 9 December 1993. See Chapter 8 for statistical comparisons of invertebrate biomass in different substrata.

often than expected. Pied stilts were present but not foraging in the flooded grass area more often than expected. They were absent from this area less often than expected.

In some of the ponds to which barley straw had been added, discrete patches of straw had not sunk. Although stilts spent most of their time foraging in ponds that had received barley straw additions, they appeared to have difficulty walking through patches of floating straw. For example, they would sometimes lift a foot very high between steps, and shake it to dislodge pieces of straw. Consequently, stilts tended to forage where the straw had sunk, and avoided foraging in the patches of floating straw.

Table 11.3. Results of Poisson regressions of pied stilts' use of ponds against biomass of three broad food types. The response variable was the number of times pied stilts were sighted foraging in each pond. See text for details. The significance of the change in deviance was assessed by a χ^2 test with one degree of freedom.

Model	Deviance	Change in deviance	% Change in deviance	*P*
Constant only	45.33			
Constant + oligochaete biomass	34.71	10.62	23.4	0.0011
Constant + chironomid biomass	31.29	14.04	31.0	0.0002
Constant + nekton biomass	36.58	8.75	19.3	0.0031

Table 11.4. Results of a χ^2 test of independence of use of ponds by pied stilts and pond substratum. E = excavated, EBS = excavated + barley straw, ES = excavated + stones, GRASS = flooded grass. Ponds were categorised according to whether pied stilts were, 1) foraging , 2) present but not foraging (other), or 3) absent. The cell χ^2 statistic (d.f. = 1) was used to estimate the statistical significance of the difference between the observed and expected number of pied stilts, for each combination of behaviour and substratum. Significant cell χ^2 statistics are indicated as follows. * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$, **** $P < 0.0001$. The overall $\chi^2 = 84.72$; $P < 0.00001$.

	E	EBS	ES	GRASS	TOTAL
Observed foraging	7	25	5	5	42
Expected foraging	13.13	13.13	13.13	2.63	
Cell χ^2	2.86	10.74**	5.03*	2.15	
Observed other	10	21	0	12	43
Expected other	13.44	13.44	13.44	2.69	
Cell χ^2	0.88	4.26*	13.44***	32.27****	
Observed absent	133	104	145	13	395
Expected absent	123.44	123.44	123.44.	24.69	
Cell χ^2	0.74	3.06	3.77	5.53*	
TOTAL	150	150	150	30	480

DISCUSSION

One objective of wetland enhancement in the Upper Waitaki Basin is to provide habitat for black stilts (Anon. 1990a). The readiness of black and pied stilts to forage and/or nest in newly created habitats is very encouraging because it suggests that future enhanced wetlands may also be used by black (and pied) stilts. However, if habitat enhancement is to be successful in the long term, managers will need to ensure that wetlands remain attractive to black stilts. To do this they will need a clear understanding of the factors that determine habitat selection by black stilts. In this study I found that the amount of times stilts were recorded foraging in ponds increased with the biomass of all three food types: Oligochaeta, Chironomidae and nekton. This finding suggests that black stilt habitat selection is influenced, at least over tens of metres, by the quantity of one, some, or all of these food types.

Because quantities of these three food types were highly intercorrelated, it is difficult to assess which one was most likely to have influenced habitat selection by stilts. Nevertheless, it is worth noting that chironomid biomass was the best predictor of habitat selection by black stilts at Ben Ohau Seepages, and that the ponds at Ben Ohau Seepages attracted more stilts, and contained more chironomid biomass (mean ± SE: 3.0 ± 0.8 $g.m^{-2}$), than ponds at the other five experimental sites. Furthermore, larval Chironomidae are widely reported to be particularly 'important' food supplies for aquatic birds (*e.g.* Danell and Sjöberg 1977, 1982; Murkin *et al.* 1982; Eldridge 1990; Gardarsson and Einarsson 1994; Rehfisch 1994), and Phillips (1991) showed that habitat selection by Pochard (*Aythya ferina*) was correlated with chironomid, but not oligochaete, density. It seems likely that wetlands that provide high chironomid biomass will be particularly attractive to black stilts. Thus, an aim in the management of wetlands for black stilts should be to maximize chironomid standing crop. A concomitant research aim should be to further investigate the chironomid-stilt relationship.

In Chapter 8, I showed that black stilt food supplies in wetlands vary with substratum, site and age of wetlands. In turn, the results of this study suggest that food supply influences habitat selection by black (and pied) stilts. Consequently, wetland managers should be able to influence black stilt habitat selection by manipulating wetland substrata. In addition, they should be able to further increase the availability of food supplies to black stilts by lowering water levels throughout the breeding season, a well established management technique for wading birds in North America (Fredrickson and Reid 1988a, 1988b; Hammer 1992; Helmers 1992).

The ability of pied stilts to forage in ponds to which barley straw had been added indicates that the addition of straw can enhance food supplies without preventing stilts from foraging. Although large areas of straw will inevitably sink in fairly discrete patches, my observations indicate that stilts are still able to move easily between the patches.

CHAPTER 12

General discussion

In this thesis I have addressed two broad questions relating to the conservation and management of habitat for black stilts (*Himantopus novaezelandiae* Gould, 1841). First, what affects - if any - do changes in lake levels have on black stilts? Second, how can habitat be manipulated to enhance food supplies for black stilts? I addressed the first question by investigating the relationships between lake levels and black stilt food supplies, foraging behaviour, habitat availability, and habitat use. To address the second question, I conducted three substratum manipulation experiments in the field, and a feeding experiment on black stilt chicks in captivity. I also surveyed food supplies at black stilt nest sites, and conducted an observational study of the use of newly created wetlands by pied and black stilts.

The management implications of these studies have been discussed in detail in their respective chapters. In this general discussion I briefly review the main findings of my research, and suggest where future research into the management of lakes and habitat for black stilts might be most profitably directed. First, however, I address the specific question that motivated my more general investigation of the effects of low lake levels on black stilts. That is, what are the likely effects on black stilts of lowering the legal minimum operating level of Lake Pukaki by five metres, from 518 m a.s.l. (metres above sea level) to 513 m a.s.l?

The above question arose during the 1992 electricity shortage when the Electricity Corporation of New Zealand (ECNZ) applied for, and was granted, special permission to use an extra five metres of water from Lake Pukaki - *i.e.* the water between 513 and 518 m a.s.l. A major concern expressed at the time by the public (James 1992; various letters to the editor in daily newspapers, late 1992), the Department of Conservation, (Hughey 1992; Murray 1992, 1993) and Conservation organisations (*e.g.* Anon. 1992), was that operating Lake Pukaki below 518 m a.s.l. might cause a shortage of food supplies for black stilts that were overwintering on the Tasman Delta of Lake Pukaki. Another concern was that, below 518 m a.s.l., parts of the Tasman Delta might be physically unsuitable for black stilts because of the formation of steep banks at the lake edge (Murray 1992).

Ultimately, ECNZ did not need to draw Lake Pukaki below 518 m a.s.l. during the 1992 electricity shortage (the minimum level in 1992 was 518.92 m a.s.l.), and black stilts were not subjected to any putative effects of extending its operating range. Nevertheless, the question regarding the effects of drawing Lake Pukaki below 518 m a.s.l. remains relevant because ECNZ is likely to reapply for access to the 'extra five metres' of water in Lake Pukaki. The water represents up to 300 GWh of storage that is available at almost nil cost to ECNZ, at a time when New Zealand's demand for electricity, and the marginal cost of electricity production is increasing (R. Sutton, Southpower, pers. comm.). That ECNZ was in the process of applying for access to this water through conventional channels, prior to the electricity shortage (Davison *et al.* 1992), demonstrates that ECNZ's desire for access to the water in Lake Pukaki was not restricted to 1992.

Because Lake Pukaki has not been drawn below 518 m a.s.l. since it was raised in 1978 (Martin 1991), predictions about the likely effects of extending the operating range must be based upon data collected within the current operating range (518 - 532 or 532.5 m a.s.l.). Reliable predictions can be made regarding the availability of food on the Tasman Delta when Lake Pukaki is below 518 m a.s.l. Food for black stilts is already extremely scarce within the lower six metres of the current operating range (*i.e.* 518 - 524 m a.s.l.), undoubtedly because the fine, inorganic substrata (silt and fine sand; this thesis Appendix 1; Irwin 1972), low temperature, silt-laden water, and the ultra-oligotrophic status of Lake Pukaki (Livingston *et al.* 1986) provide an unsuitable environment for most aquatic macro-invertebrates (Ward 1992). It seems likely that the little food that is available at the lake edge of the Tasman Delta, between 518 and *c.* 524 m a.s.l., comprises not the resident benthos, but invertebrates that have been carried into the lake by streams. Below 518 m a.s.l., food is also likely to be scarce at the lake edge, but invertebrates would probably continue to drift into the lake and be deposited in the littoral zone. The scarcity of food between 518 and *c.* 524 m a.s.l. was reflected in a tendency for black stilts to feed there at slower rates than at higher lake levels. It is likely that, if the level of Lake Pukaki fell below 518 m a.s.l., feeding rates would be similar to those between 518 and 524 m a.s.l. That is, they would be highly variable but relatively low on average.

The type of physical habitat that would be available on the Tasman Delta if the level of Lake Pukaki fell below 518 m a.s.l. is also largely predictable: the delta will provide increasingly large expanses of open, unvegetated habitat as the lake declines. Approximately 5 km^2 of such habitat is available between 518 and 532 m a.s.l. This habitat will still be available to black stilts, regardless of what happens to the lake below 518 m a.s.l. However, the physical nature of the habitat at the lake edge may change as the level of Lake Pukaki declines and finer substrata are exposed. The

fine substrata of the Upper Waitaki Lakes are prone to erosion (Mark and Kirk 1987; Mark 1987), and at low lake levels the lake edge of the Tasman Delta may be unsuitable for black stilts because of the presence of steep banks.

In the long term, the best indicator of the value of the Tasman Delta as black stilt habitat is probably the number of black stilts that choose to use the delta. Numbers of black stilts sighted on the Tasman Delta during the winters of 1984 - 1994 were highly variable and unrelated to lake level, suggesting that lake level does not strongly influence black stilts on the Tasman Delta, at least within the range of levels I investigated. On the basis of field observations, I suspect that weather-related factors such as floods, ice formation (on the deltas and elsewhere), wind, and wave size influence the number of black stilts on the Tasman Delta far more strongly than lake levels. Nevertheless, I recommend that any extension of the legal operating range of Lake Pukaki is accompanied by ongoing monitoring of the responses of black stilts. Such monitoring should focus on the numbers of black stilts that use the Tasman Delta, and ultimately on their survival and breeding success.

In contrast to Lake Pukaki, declines in the level of Lake Benmore were associated with dramatic increases in the numbers of black stilts and the availability of habitat and food supplies on the Ahuriri Delta, and also with increases in numbers of black stilts and availability of habitat on the Tekapo/Ohau Delta. As discussed in Chapter 5, black stilts would potentially benefit in at least four ways from intentional drawdowns of Lake Benmore. Future research could profitably be directed toward investigating whether these putative benefits are real. For example, would intentional drawdowns increase the number of black stilts that form pairs? And would drawdowns of Lake Benmore, combined with lake-side releases, increase the probability that captive-reared black stilts would survive? Research aimed at addressing such questions would need to be conducted over a long term because of inevitably low sample sizes. However, such research would cost little because the data are already being collected during the normal course of black stilt management.

Unlike Lakes Pukaki and Benmore, changes in the levels of Lakes Tekapo and Ohau did not strongly affect any aspects of the ecology of black stilts on the Godley, Cass or Hopkins Deltas. Numbers of black stilts on the Cass Delta decreased slightly as the level of Lake Tekapo declined, but total numbers of black stilts on Lake Tekapo (*i.e.* on the Godley and Cass Deltas combined) were not related to lake level. Few black stilts used the Hopkins Delta, perhaps because it provided only a small area of unvegetated, flat habitat. The low numbers of black stilts and small area of

black stilt habitat on the Hopkins Delta suggest that lakes that vary little in level may provide poor habitat for black stilts. However, a powerful test of this hypothesis would require a larger sample of lake deltas than is available in the Upper Waitaki Basin.

The research reported in Part II of this thesis demonstrates that constructed or manipulated wetlands can provide abundant and suitable food supplies for black stilts. An initial small-scale field experiment showed that adding various substrata to wetlands could strongly influence invertebrate community composition and standing crop. Two large-scale field experiments demonstrated that substratum additions, construction methods and 'site' interacted to influence the type and amount of food present in constructed wetlands. Generally, invertebrate community composition and standing crop appeared to be influenced most strongly by local, site-specific conditions such as particle size composition and organic matter content of the substratum (Chapter 8). However, at some sites, substratum additions and construction methods strongly influenced aquatic invertebrate communities. Therefore, to provide the most suitable foraging habitat for black stilts, managers need to carefully consider the likely effects of 'site', substratum additions and construction methods.

One general pattern was evident from the pond experiment; regardless of substratum manipulations, invertebrate communities in wetlands at any particular site tended to converge, over time, in taxonomic composition and relative biomass of different food types. Thus, communities became more saturated with species, and chironomid biomass tended to decline, while oligochaete and mollusc biomass increased as ponds aged. The biomass of 'nektonic' invertebrates tended to increase over the first year or two, and then decline. If larval Chironomidae and nektonic invertebrates are the most attractive foods for black stilts, as suggested by my field observations (Chapters 3, 11), wetlands in early stages of succession should provide the most suitable food supplies for black stilts. 'Resetting' wetlands by physically disturbing them, or by manipulating water levels, may ensure that they continue to provide appropriate food supplies for black stilts.

A valuable finding of the wetland research was that wetlands constructed in late winter (August) could provide abundant food resources within three months, and would sometimes be used by black (and pied) stilts immediately. The range of invertebrate biomass in the experimental wetlands was similar to that at black stilt nest sites. However, if managers choose the most suitable sites and substrata, constructed wetlands should provide more abundant food supplies than most natural nest sites.

An assumption underlying the rationale for my habitat enhancement research was that the type and amount of food can influence habitat selection by black stilts. Thus, providing highly suitable foraging habitat should encourage black stilts to nest within wetlands that are relatively safe from predators and other threats. Although this seems a reasonable assumption, and is supported by field observations (Chapter 11), the extent to which food influences habitat selection is unknown. For example, black (and pied) stilts appeared to be attracted to newly created or recently disturbed habitats (Chapter 11), which provided both abundant food supplies and physically suitable habitats. Research aimed at improving our understanding of the relative influence of type and amount of food and habitat structure should help managers to focus on the factors that most strongly influence habitat selection by black stilts. If managers can provide black stilts with physically suitable habitats that are as free from predators as possible, and that have abundant, useable food supplies, the prospect for recovery of the black stilt population in the Upper Waitaki Basin is excellent.

Acknowledgements

Many many people lent a hand in completing the research reported here, and in producing this document. I am especially grateful to my supervisor, Mike Winterbourn, for being patient and for encouraging me to improve my ability to communicate on paper. Thanks Mike. Thanks also to my associate supervisor, Ian McLean, for always helping when I asked. I am particularly indebted to Richard Maloney, who played a large part in initiating both the lake level and the wetland research, and who kept me on my toes by asking lots of gnarly questions. Good stuff - guess I owe you a few.

My research was made possible by the Electricity Corporation of New Zealand (ECNZ), which provided funds, and by the Department of Conservation in Twizel, which provided logistic support and paid for pond construction and some sample sorting. I'm grateful to Greg Carson and Barry Knox of ECNZ who helped smooth the bureaucratic bumps. Staff of the Black Stilt Recovery Programme and of Project River Recovery were always prepared to share their time, enthusiasm, experience, and often their homes. Thanks heaps Dave, Simon, Christine, Alicia, Richard, Ron, Lynn, Nikki, Bert, Kirsten, and Margot. Simon, a special thank you for demonstrating your unique honey-softening technique without me even having to ask. Thanks also to Tim, who provided accommodation and good company in the hills, to my mother for all that tea and cake halfway between Christchurch and Twizel, and to the other people who provided good company and a place to stay: Lynn and Stu, Debbie, Amelia, Bert, Natascha, and Bernado.

I am grateful to Andrew from NIWA, Lake Tekapo, who provided lake level data, and to Peter Hall of Workscorp, Timaru, for dragging out Lake Pukaki sediment and shore profile data. I also thank Lady Isaac (Isaac Construction) and Anne Richardson for the tour of Peacock Springs, and the opportunity to see their black stilt facilities.

Pond sampling was made easier and much much more enjoyable thanks to the help, company and endurance of Jim Hobsley, Helen Brook, Andrew Firth and Kate Hobsley. Yeah, there *was* a lot of mud, wasn't there, but didn't the coffee, sun and all that open space make it worthwhile? Sorry about the lack of coffee, Kate. I collected a lot of large, muddy, detritus-packed samples in the course of my research. I am eternally grateful to Kate for sorting most of them.

I shared my room in the Zoo Department for most of the duration of my studies with Jon Harding and Mandy Tocher, and I have to say that there was never a dull moment. For your friendship (both of you), good humour (Jon), and abuse (Mandy), thank you; it was a fine time. Those hours in Room 523 were also made entertaining and friendly thanks to Sue, Nikolai and Jenny. Thanks. To the technicians in the Zoo Department, especially Bruce, Dave G., Nick, Pete and Gavin, thanks for always being willing and able to help. It is much appreciated. Jan MacKenzie, I don't think I needed technical help from you during my research, but you have helped enormously over the years. Thank you, you are a phenomenon, and I still reckon there are at least two of you. Thanks also to Tracey and Lyn for helping in all sorts of ways, and for tolerating my inability to dial the right fax number.

My research has benefited, I hope, from discussions with many people including, in addition to most of the above-mentioned people, Richard Duncan, Dave Schiel, Bruce Waldman, Ashley Sparrow, Mike Hobsley, Garth Fletcher, Chris Frampton, Clare Veltman, and Ray Pierce. Thank you for taking the time to think about my research.

Finally, to Kate, thanks for everything.

References

Adams, L. K. 1995. Reintroduction of juvenile black stilts to the wild. M.Sc. thesis. Department of Zoology, University of Canterbury, Christchurch, New Zealand.

Andrews, J., and Kinsman, D., editors. 1990. *Gravel Pit Restoration for Wildlife: A Practical Manual*. RSPB, Sandy, U.K. 184 pp.

Anon. 1981a. Benmore Power Station Operating Instruction No. 203, Amendment E: February 1981 Spillway and Spillway Channel.

Anon. 1981b. Lake Pukaki Spillway, Operating Instruction No. 25, Amendment B February 1981.

Anon. 1988. Flood Operating Instructions Ohau A, B, C Power Stations and Associated Canals and Spillways, 11 May 1988.

Anon. 1990a. Compensatory funding agreement between The Department of Conservation and The Electricity Corporation of New Zealand.

Anon. 1990b. Tekapo A station (and Lake Tekapo) Spillway Operating Instructions, August 1990.

Anon. 1992. Conservation update: black stilt even more endangered. *Forest and Bird* **23**(3):2.

Bell, B. D. 1986. *The Conservation Status of New Zealand Wildlife*. New Zealand Wildlife Service, Department of Internal Affairs, Wellington. 103 pp.

Britton, R. H. 1983. Managing the prey fauna. Pages 92-97 *in* D. A. Scott, editor. *Managing Wetlands and Their Birds*. Proceedings of the Third Technical Meeting on Western Palearctic Migratory Bird Management. International Waterfowl Research Bureau, Slimbridge.

Budgeon, L. 1977. Aspects of the biology of the black stilt (*Himantopus novaezealandiae* Gould) in the Upper Waitaki River Basin. B.Sc. (Hons) thesis. University of Canterbury, New Zealand.

Buller, W. L. 1875. On the genus *Himantopus* in New Zealand. *Transactions of the New Zealand Institute* 7:220-224.

Buller, W. L. 1888. *A History of the Birds of New Zealand*, 2nd Edition. The Author, London.

Burger, J. 1980. Age differences in foraging black-winged stilts in Texas. *The Auk* 97:633-636.

Cézilly, F., Boy, V., Green, R. E., Hirons, G. J. M., and Johnson, A. R. 1995. Interannual variation in greater flamingo breeding success in relation to water levels. *Ecology* 76(1):20-26.

Chapman, A., and Lewis, M. 1976. *An Introduction to the Freshwater Crustacea of New Zealand*. Collins, Auckland. 261 pp.

Cody, M. L., editor. 1985. *Habitat Selection in Birds*. Academic Press, Orlando. 558 pp.

Colwell, M. A., and Landrum, S. L. 1993. Nonrandom shorebird distribution and fine-scale variation in prey abundance. *The Condor* 95:94-103.

Cowley, D. R. 1978. Studies on the larvae of New Zealand Trichoptera. *New Zealand Journal of Zoology* 5:639-750.

Cross, D. H., editor. 1990. *Waterfowl Management Handbook*. United States Department of the Interior, Fish and Wildlife Service, Washington, D.C.

Cullen, S. A. 1994. Black-necked stilt foraging site selection and behavior in Puerto Rico. *Wilson Bulletin* 106:508-513.

Cummins, K. W. 1962. An evaluation of some techniques for the collection and analysis of benthic samples with special emphasis on lotic waters. *The American Midland Naturalist* 67:477-504.

Danell, K., and Sjöberg, K. 1977. Seasonal emergence of chironomids in relation to egglaying and hatching of ducks in a restored lake (northern Sweden). *Wildfowl* **28**:129-135.

Danell, K., and Sjöberg, K. 1982. Successional patterns of plants, invertebrates and ducks in a man-made lake. *Journal of Applied Ecology* **19**:395-409.

Davison, R., Carter, R. P., and Gough, R. M. 1992. *The Report of the Electricity Shortage Review Committee*. The Department of Prime Minister and Cabinet, New Zealand, Wellington. 124 pp.

Driver, E. A. 1981. Calorific values of pond invertebrates eaten by ducks. *Freshwater Biology* **11**:579-581.

Driver, E. A., Sugden, L. G., and Kovach, R. J. 1974. Calorific, chemical and physical values of potential duck foods. *Freshwater Biology* **4**:281-292.

Dunbar, J. D. 1978. The feeding niche of the Black Stilt *Himantopus novaezealandiae* Gould in relation to the feeding niches of other aquatic birds in the Upper Waitaki River Basin. Unpublished Report, Department of Zoology, University of Canterbury, New Zealand.

Eldridge, J. 1990. Aquatic invertebrates important for waterfowl production. *in* D. H. Cross, editor. Fish and Wildlife Service Leaflet 13.3.3: *Waterfowl Management Handbook*. U.S. Department of the Interior Fish and Wildlife Service, Washington, D.C.

Espin, P. M. J., Mather, R. M., and Adams, J. 1983. Age and foraging success in black-winged stilts *Himantopus himantopus*. *Ardea* **71**:225-228.

Evans, J., editor. 1994. *New Zealand Official Yearbook*. Statistics New Zealand, Wellington. 587 pp.

Fitzharris, B. B. 1992. The 1992 electricity crisis and the role of climate and hydrology. *New Zealand Geographer* **48**(2):79-83.

Fitzharris, B. B., Mansergh, G. D., and Soons, J. M. 1992. Basins and lowlands of the South Island. Pages 407-423 *in* J. M. Soons and M. J. Selby, editors. *Landforms of New Zealand*, 2nd Edition. Longman Paul, Auckland.

Francis, D. R., and Kane, T. C. 1995. Effect of substrate on colonization of experimental ponds by Chironomidae (Diptera). *Journal of Freshwater Ecology* **10**(1):57-63.

Fredrickson, L. H., and Reid, F. A. 1988. Invertebrate response to wetland management. *in* D. H. Cross, editor. Fish and Wildlife Service Leaflet 13.3.1: *Waterfowl Management Handbook*. United States Department of the Interior Fish and Wildlife Service, Washington, D.C.

Fredrickson, L. H., and Reid, F. A. 1988. Waterfowl use of wetland complexes. *in* D. H. Cross, editor. Fish and Wildlife Service Leaflet 13.2.1: *Waterfowl Management Handbook*. United States Department of the Interior Fish and Wildlife Service, Washington, D.C.

Gabor, T. S., Murkin, H. R., Stainton, M., P, Boughen, J. A., and Titman, R. D. 1994. Nutrient additions to wetlands in the Interlake region of Manitoba, Canada: effects of a single pulse addition in spring. *Hydrobiologia* **279/280**:497-510.

Gardarsson, A., and Einarsson, A. 1994. Responses of breeding duck populations to changes in food supply. *Hydrobiologia* **279/280**:15-27.

Giles, N. 1986. Differences in the ecology of wet-dug and dry-dug gravel pit lakes. *Game Conservancy Annual Review* **18**:130-133.

Goriup, P. D. 1982. Behaviour of Black-winged stilts. *British Birds* **75**:12-24.

Goss-Custard, J. D. 1969. The winter feeding ecology of the redshank *Tringa totanus*. *Ibis* **111**:338-356.

Goss-Custard, J. D. 1984. Intake rates and food supply in migrating and wintering shorebirds. Pages 233-270 *in* J. Burger and B. L. Olla, editors. *Behavior of Marine Animals, 6: Shorebirds: Migration and Foraging Behavior*. Plenum Press, New York.

Goss-Custard, J. D., Jenyon, R. A., Jones, R. E., Newbery, P. E., and Williams, R. B. 1977a. The ecology of The Wash. II. Seasonal variation in the feeding conditions of wading birds (Charadrii). *Journal of Applied Ecology* **14**:701-719.

Goss-Custard, J. D., Kay, D. G., and Blindell, R. M. 1977b. The density of migratory and overwintering redshank, *Tringa totanus* (L.) and curlew, *Numenius arquata* (L.), in relation to the density of their prey in south-east England. *Estuarine Coastal Marine Science* **5**:497-510.

Gould, J. 1841. [Description of a new species of *Himantopus* from New Zealand]. *Proceedings of the Zoological Society of London*:8.

Graveland, J., and Van Gijzen, T. 1994. Arthopods and seeds are not sufficient as calcium sources for shell formation and skeletal growth in passerines. *Ardea* **82**(2):299-314.

Green, B. S. 1988. Genetic variation and management of black stilts, *Himantopus novaezealandiae* and pied stilts, *H. h. leucocephalus* (O. Charadriiformes). M.Sc. (Hons.) thesis. Victoria University, Wellington, New Zealand.

Greig, C. A. 1973. A survey of the littoral fauna of two man made lakes. (Lake Aviemore and Lake Waitaki.). M.Sc. fourth year project. Department of Zoology, University of Canterbury, Christchurch, New Zealand.

Hale, W. G. 1980. *Waders*. Collins, London. 320 pp.

Hamilton, R. B. 1975. Comparative behavior of the American Avocet and the Black-necked stilt (Recurvirostridae). Ornithological Monographs **17**.

Hammer, D. A. 1992. *Creating freshwater wetlands*. Lewis Publishers, Boca Raton.

Hands, H. M., Ryan, M. R., and Smith, J. W. 1991. Migrant shorebird use of marsh, moist-soil, and flooded agricultural habitats. *Wildlife Society Bulletin* **19**(4):457-464.

Hayman, P., Marchant, J., and Prater, T. 1986. *Shorebirds: an identification guide to the waders of the world*. Croom Helm, London. 412 pp.

Helmers, D. L. 1992. *Shorebird Management Manual*. Western Hemisphere Shorebird Reserve Network, Manomet. 58 pp.

Hockey, P. A. R., Navarro, R. A., Kalejta, B., and Velasquez, C. R. 1992. The riddle of the sands: why are shorebird densities so high in southern estuaries? *The American Naturalist* **140**(6):961-979.

Holdaway, R. N. 1995. A fossil record of the black stilt *Himantopus novaezelandiae* Gould 1841. *New Zealand Natural Sciences* **22**:69-74.

Hughey, K. 1992. Effects of lowering Lake Pukaki on black stilts. Letter from the Regional Conservator to the Minister of Conservation, dated 22 June 1992.

Hume, D. K. 1995. Anti-predator training: an experimental approach in reintroduction biology. M.Sc. thesis. Department of Zoology, University of Canterbury, Christchurch, New Zealand.

Hunt, P. C., and Jones, J. W. 1972. The effect of water level fluctuations on a littoral fauna. *Journal of Fish Biology* **4**:385-394.

Hutton, F. W. 1871. *Catalogue of the Birds of New Zealand with Diagnoses of the Species*. James Hughes, Wellington.

Hynes, H. B. N. 1961. The effect of water-level flucuations on littoral fauna. *Verhandlungen der Internationalen Vereinigung für Theoretische und Angewandte Limnologie* **14**:652-656.

International Commission on Zoological Nomenclature. 1985. *International Code of Zoological Nomenclature*, 3rd Edition. International Trust for Zoological Nomenclature in association with the British Museum of Natural History, London.

Irwin, J. 1972. Sediments of Lake Pukaki, South Island, New Zealand. *New Zealand Journal of Marine and Freshwater Research* **6**:482-491.

James, C. 1992. Black stilt blues. *Far Eastern Economic Review* **155**(29):23.

James, M., James, G., Hawes, I., and Hicks, M. 1995. *The effects of lake level changes on the ecology of Lake Coleridge*. National Institute of Water and Atmosphere, Christchurch, Consultancy report no. ELE906. 62 pp.

Jowett, I. G., Richardson, J., Biggs, B. J. F., Hickey, C. W., and Quinn, J. M. 1991. Microhabitat preferences of benthic invertebrates and the development of generalised *Deleatidium* spp. habitat suitablility curves, applied to four New Zealand rivers. *New Zealand Journal of Marine and Freshwater Research* 25:187-199.

Kelley, J. R. jr, Laubhan, M. K., Reid, F. A., Wortham, J. S., and Fredrickson, L. H. 1993. Options for water-level control in developed wetlands. *in* D. H. Cross, editor. Fish and Wildlife Service Leaflet 13.4.8: *Waterfowl Management Handbook*. United States Department of the Interior Fish and Wildlife Service, Washington D.C.

Kinsky, F. C. 1970. *Annotated Checklist of the Birds of New Zealand, Including the Birds of the Ross Dependency*. Reed, Wellington. 96 pp.

Kirk, R. M., and Henriques, P. R. 1986. Physical and biological aspects of shoreline change: Lake Ohau, South Island, New Zealand. *Journal of Shoreline Management* 2:305-326.

Knighton, M. D., editor. 1985. *Water Impoundments for Wildlife: A Management Workshop*. U.S. Department of Agriculture, St. Paul, Minnesota.

Kusler, J. A., and Kentula, M. E., editors. 1990. *Wetland Creation and Restoration: the status of the science*. Island Press, Washington, D.C. 594 pp.

Lellák, J. 1965. The food supply as a factor regulating the population dynamics of bottom animals. *Mitteilungen Internationale Vereinigung für Theoritische und Angewandte Limnologie* 13:128-138.

Livingston, M. E., Biggs, B. J., and Gifford, J. S., editors. 1986. Water and Soil Miscellaneous Publication, 81: *Inventory of New Zealand Lakes. Part II South Island*. Water and Soil Directorate, Ministry of Works and Development, Wellington. 193 pp.

Lovette, I. J., and Holmes, R. T. 1995. Foraging behavior of american redstarts in breeding and wintering habitats: implications for relative food availability. *The Condor* **97**:782-791.

Lyon, J. C., Drobney, R. D., and Olson, C. E. J. 1986. Effects of Lake Michigan water levels on wetland soil chemistry and distribution of plants in the Straits of Mackinac. *Journal of Great Lakes Research* **12**(3):175-183.

Mark, A. F. 1987. Lake level control. Pages 113-123 *in* P. R. Henriques, editor. *Aquatic Biology and Hydroelectric Power Developments in New Zealand*. Oxford, Oxford.

Mark, A. F., and Kirk, R. M. 1987. Lake levels and lakeshore erosion. Pages 215-222 *in* W. N. Vant, editor. *Lake Managers Handbook*. Water and Soil Directorate, Ministry of Works and Development, Wellington, Water and Soil Miscellaneous Publication number 103.

Martin, J. E., editor. 1991. *People, Politics and Power Stations: Electric Power Generation in New Zealand 1880-1990*. Bridget Williams Books and the Electricity Corporation of New Zealand, Wellington. 316 pp.

McFarlane, A. G. 1951. Caddisfly larvae (Trichoptera) of the family Rhyacophilidae. *Records of the Canterbury Museum* **5**(5):267-289.

McFarlane, A. G. 1976. A generic revision of New Zealand Hydropsychinae (Trichoptera). *Journal of the Royal Society of New Zealand* **6**(1):23-35.

McFarlane, A. G. 1990. A generic key to the late instar larvae of the New Zealand Trichoptera (Caddisflies). *Records of the Canterbury Museum* **10**(3):25-38.

McLachlan, A. J. 1970. Some effects of annual fluctuations in water level on the larval chironomid communities of Lake Kariba. *Journal of Animal Ecology* **39**:79-90.

McLachlan, A. J. 1974. The development of chironomid communities in a new temperate impoundment. *Entomologisk Tidskrift* **95 Supplement**:162-171.

McLachlan, A. J., and Cantrell, M. A. 1976. Sediment development and its influence on the distribution and tube structure of *Chironomus plumosus* L. (Chironomidae, Diptera) in a new impoundment. *Freshwater Biology* 6:437-443.

McLellan, I. D. 1993. Fauna of New Zealand, 27: *Antarctoperlinae (Insecta: Plecoptera)*. Manaaki Whenua Press, Lincoln, New Zealand.

Merritt, R. W., Cummins, K. W., and Burton, T. M. 1984. The role of aquatic insects in the processing and cycling of nutrients. Pages 134-163 *in* V. H. Resh and D. M. Rosenberg, editors. *The Ecology of Aquatic Insects*. Praeger, New York.

Merton, J. M. 1977. Feeding habits of the Black Stilt, *Himantopus novaezealandiae*, in the Upper Waitaki Basin. B.Sc. (Hons.) thesis. Zoology Department, University of Canterbury, Christchurch, New Zealand.

Michaelis, F. B. 1974. The ecology of Waikoropupu Springs. Ph.D. thesis. Department of Zoology, University of Otago, New Zealand.

Minshall, G. W. 1984. Aquatic insect-substratum relationships. Pages 358-400 *in* V. H. Resh and D. M. Rosenberg, editors. *The Ecology of Aquatic Insects*. Praeger, New York.

Molloy, J., Davis, A., and Tisdall, C., editors. 1994. *Setting Priorities for the Conservation of New Zealand's Threatened Plants and Animals*, 2nd Edition. Deparment of Conservation, Wellington. 64 pp.

Moon, H. P. 1935. Flood movements of the littoral fauna of Lake Windermere. *Journal of Animal Ecology* 4:216-228.

Moss, B. 1988. *Ecology of fresh waters*, 2nd Edition. Blackwell Scientific Publications, Oxford. 417 pp.

Murkin, H. R., and Kadlec, J. A. 1986. Responses by benthic macroinvertebrates to prolonged flooding of marsh habitat. *Canadian Journal of Zoology* 64:65-72.

Murkin, H. R., Kaminski, R. M., and Titman, R. D. 1982. Responses by dabbling ducks and aquatic invertebrates to an experimentally manipulated cattail marsh. *Canadian Journal of Zoology* **60**:2324-2332.

Murkin, H. R., Pollard, J. B., Stainton, M., P, Boughen, J. A., and Titman, R. D. 1994. Nutrient additions to wetlands in the Interlake region of Manitoba, Canada: effects of periodic additions throughout the growing season. *Hydrobiologia* **279/280**:483-495.

Murray, D. P. 1992. Black stilt winter trend count 1992. Unpublished Department of Conservation report.

Murray, D. P. 1993. Black stilt project 1992/93 breeding season report. Unpublished Department of Conservation report.

Murray, D. P. 1994. Black stilt project 1993/94 breeding season report. Unpublished Department of Conservation report.

Murray, D. P. 1996. Black stilt project 1995/96 breeding season report. Unpublished Department of Conservation Report.

Neter, J., Wasserman, W., and Kutner, M. H. 1985. *Applied Linear Statistical Models*, 2nd Edition. Irwin, Homewood, Illinois. 1127 pp.

Nursall, J. R. 1952. The early development of a bottom fauna in a new power reservoir in the Rocky Mountains of Alberta. *Canadian Journal of Zoology* **30**:387-409.

O'Driscoll, R., and Veltman, C. 1992. Viability of simulated black stilt populations. Unpublished report to the Black Stilt Recovery Group.

Oliver, W. R. B. 1955. *New Zealand Birds*, 2nd Edition. A.H. and A.W. Reed, Wellington. 661 pp.

Ornithological Society of New Zealand Checklist Committee. 1953. *Checklist of New Zealand Birds*. Reed, Wellington. 80 pp.

Pascoe, A. 1995. The effects of vegetation removal on rabbits (*Oryctolagus cuniculus*) and small mammalian predators in braided riverbeds in the Mackenzie Basin. M.Sc. thesis. Department of Zoology, University of Otago, Dunedin, New Zealand.

Paterson, C. G., and Fernando, C. H. 1969. The macro-invertebrate colonization of a small reservoir in Eastern Canada. *Verhandlungen der Internationalen Vereinigung für Theoretische und Angewandte Limnologie* **17**:126-136.

Peters, W. L., and Campbell, I. C. 1991. Ephemeroptera. Pages 279-293 *in* CSIRO, editor. *The Insects of Australia, A Textbook for Students and Research Workers*. Volume 1. Melbourne University Press, Carlton.

Phillips, V. E. 1991. Pochard *Aythya ferina* use of chironomid-rich feeding habitat in winter. *Bird Study* **38**:118-122.

Pierce, R. J. 1982a. A comparative ecological study of pied and black stilts in South Canterbury. Ph.D. thesis. University of Otago, New Zealand.

Pierce, R. J. 1982b. A good nesting season for black stilts at Lake Tekapo. *Forest and Bird* **14**(2):30-32.

Pierce, R. J. 1983. The charadriiforms of a high country river valley. *Notornis* **30**:169-185.

Pierce, R. J. 1984a. The changed distributions of stilts in New Zealand. *Notornis* **31**:7-18.

Pierce, R. J. 1984b. Plumage, morphology and hybridisation of New Zealand stilts (*Himantopus* spp.). *Notornis* **31**:106-130.

Pierce, R. J. 1985. Feeding methods of stilts (*Himantopus* spp.). *New Zealand Journal of Marine and Freshwater Research* **12**:467-472.

Pierce, R. J. 1986a. Differences in susceptibility to predation during nesting between pied and black stilts (*Himantopus* spp.). *The Auk* **103**:273-280.

Pierce, R. J. 1986b. Foraging Responses of stilts (*Himantopus* spp.: Aves) to changes in behaviour and abundance of their riverbed prey. *New Zealand Journal of Marine and Freshwater Research* **20**:17-28.

Pierce, R. J. 1987. Predators in the MacKenzie Basin: their diet, population dynamics, and impact on birds in relation to the abundance and availability of their main prey (rabbits). Unpublished Wildlife Service Report, New Zealand Department of Internal Affairs.

Puttick, G. M. 1984. Foraging and activity patterns in wintering shorebirds. Pages 203-231 *in* J. Burger and B. L. Olla, editors. *Behavior of Marine Mammals, 6: Shorebirds: Migration and Foraging Behaviour*. Plenum Press, New York.

Quinn, J. M., and Hickey, C. W. 1990. The magnitude of the effects of substrate particle size, recent flooding, and catchment development on benthic invertebrates in 88 New Zealand rivers. *New Zealand Journal of Marine and Freshwater Research* **24**:411-427.

Raastad, J. E., Lillehammer, A., Lillehammer, L., Kaasa, H., and Eie, J. A. 1993. Effect of habitat improvement on Atlantic salmon in the regulated river Suldalslågen. *Regulated Rivers: Research and Management* **8**:95-102.

Rebergen, A. L. 1993. Factors influencing the predation of eggs and young of the banded dotterel (*Charadrius bicintus*) on some braided rivers in the Mackenzie Basin. Diploma of Wildlife Management Report. Department of Zoology, University of Otago, Dunedin, New Zealand.

Reed, C. E. M. 1986. The maintenance and reproductive behaviour of Black Stilts (*Himantopus novaezealandiae*) in captivity and implications for management of this rare species. M.Sc. (Hons.) thesis. Massey University, Palmerston North, New Zealand.

Reed, C. E. M. 1994a. Causes of mortality in black stilts *Himantopus novaezelandiae* in captivity. *International Zoo Yearbook* **33**:129-135.

Reed, C. E. M. 1994b. Hand-rearing and breeding the endangered black stilt *Himantopus novaezelandiae* at Twizel. *International Zoo Yearbook* **33**:125-128.

SAS Institute. 1989. *SAS/STAT Users guide, version 6*, 4th Edition. Volume 1-2. SAS Institute Inc., Cary, North Carolina.

Schneller-McDonald, K., Ischinger, L. S., and Auble, G. T. 1990. Wetland creation and restoration: description and summary of the literature. *Biological Report* 90.

Scott, D. A., editor. 1983. *Managing Wetlands and Their Birds:* A Manual of Wetland and Waterfowl Management: Proceedings of the Third Technical Meeting on Western Palearctic Migratory Bird Management., Slimbridge, England.

Siegel, J., editor. 1992. *STATISTIX Version 4.0 User's Manual*, 2nd Edition. Analytical Software, St. Paul, Minnesota. 319 pp.

Soper, M. F. 1967. Some observtions on black stilts. *Notornis* **14**:8-10.

Soper, M. F. 1976. *New Zealand Birds*, 2nd Edition. Whitcoulls, Christchurch, New Zealand. 251 pp.

Stark, J. D. 1990. Macroinvertebrates associated with submerged aquatic plants in Lake Benmore and their relationship to fluctuating lake levels. Report prepared for South Island Hydro Group, Electricorp Production, Dunedin, by The Cawthron Institute, Nelson.

StatSoft Incorporated. 1994. *STATISTICA for the Windows Operating System*. StatSoft Incorporated, Tulsa.

Stead, E. F. 1932. *The Life Histories of New Zealand Birds*. Search, London. 162 pp.

Stout, V. M. 1976. Class Arachnida. Pages 261 *in* A. Chapman and M. Lewis, editors. *An Introduction to the Freshwater Crustacea of New Zealand*. Collins, Auckland.

Street, M. 1977. The food of mallard ducklings in a wet gravel quarry, and its relation to duckling survival. *Wildfowl* **28**:113-125.

Street, M. 1983. The use of waste straw to promote the production of invertebrate foods for waterfowl in man-made wetlands. Pages 98-103 *in* D. A. Scott, editor. *Managing Wetlands and their Birds*. Proceedings of the Third Technical Meeting on Western Palearctic Migratory Bird Management. International Waterfowl Research Bureau, Slimbridge.

Street, M., and Titmus, G. 1979. The Colonisation of experimental ponds by Chironomidae (Diptera). *Aquatic Insects* **1**(4):233-244.

Street, M., and Titmus, G. 1982. A field experiment on the value of allochthonous straw as food and substratum for lake macro-invertebrates. *Freshwater Biology* **12**:403-410.

Tinarelli, R. 1987. Wintering biology of the black-winged stilt in the Mahgreb region. *Wader Study Group Bulletin* **50**:30-34.

Turbott, E. G., editor. 1990. *Checklist of the Birds of New Zealand and the Ross Dependency, Antarctica*, 3rd Edition. Random Century in association with the Ornithological Society of New Zealand, . 247 pp.

Underwood, A. J. 1981. Techniques of analysis of variance in experimental marine biology and ecology. *Oceanography and Marine Biology Annual Review* **19**:513-605.

Velasquez, C. R. 1992. Managing Artificial Saltpans as a Waterbird Habitat: Species' Responses to Water Level Manipulation. *Colonial Waterbirds* **15**(1):43-55.

Voshell, J. R., and Simmons, G. M. J. 1984. Colonization and succession of benthic macroinvertebrates in a new reservoir. *Hydrobiologia* **112**:27-39.

Ward, J. V. 1992. *Aquatic Insect Biology. Volume 1. Biology and Habitat*. Wiley, New York. 438 pp.

Williams, G. R., and Given, D. R. 1981. *The Red Data Book of New Zealand*. Nature Conservaton Council, Wellington.

Winer, B. J. 1971. *Statistical Concepts in Experimental Design*, 2nd Edition. McGraw-Hill, New York. 907 pp.

Winter, J. W. 1964. Survey of Lake Roxburgh, a recent hydro-electric dam. *Proceedings of the New Zealand Ecological Society.* **11**:16-23.

Winterbourn, M. J. 1973. A guide to the freshwater Mollusca of New Zealand. *Tuatara* **20**(3):141-154.

Winterbourn, M. J., and Gregson, K. L. D. 1989. Guide to the aquatic insects of New Zealand. *Bulletin of the Entomological Society of New Zealand* **9**:96 p.

Wood, D. S. 1985. A note on the nomenclature of the New Zealand stilts (*Himantopus*). *Notornis* **32**:152-155.

Zar, J. H. 1984. *Biostatistical Analysis*, 2nd Edition. Prentice Hall, Englewood Cliffs. 718 pp.

APPENDIX 1

Lake Pukaki bottom sediment survey

The data in this appendix were reproduced from Works Consultancy Services Report No. G92/167, with the permission of their client, the Electricity Corporation of New Zealand. Sediment samples were taken from the bed of Lake Pukaki using a bottom grab sampler operated from a boat. Lake bed sediments were sampled at three depths (*c.* 518, 516 and 513 m a.s.l.) on four longitudinal (north-south) transects. Particle size distribution (Table A1.1) was determined by wet sieving in accordance with NZS4402: 1986 Test 2.8.1. Full details of the survey methods, including coordinates of sample sites A- L, are given in the above report.

Table A1.1. Particle size distribution in sediment samples taken from Lake Pukaki. Numbers show the percentage of samples by mass that passed through sieves of different apertures. Particle size class terminology used in this thesis follows Cummins (1962). Thus, silt consists of particles 0.0039 - 0.063 mm in diameter, and sand consists of particles 0.063 - 2.0 mm in diameter (for the purposes of this thesis, I did not discriminate among different classes of sand).

Site	A	B	C	D	E	F	G	H	I	J	K	L
	Depth (m a.s.l.)											
Sieve aperture (mm)	518	516	513	518	516	513	518	516	513	518	516	513
0.600	100			100			100			100		
0.300	97			96			99			99		
0.212	87			82			96			93		
0.150	60	100	100	55			87	100	100	73	100	
0.075	22	90	97	16	100	100	21	98	99	26	97	
0.063	16	85	94	12	99	99	12	96	98	18	96	
0.045	11	75	89	8	96	99	6	92	98	10	96	100

APPENDIX 2

Black stilt sub-populations

Department of Conservation staff have categorised their recorded sightings of wild black stilts in the Upper Waitaki Basin into 11 'areas'. Each area comprises 3 - 12 wetlands (Table A2.1). A knowledge of the number and identity of black stilts in each area, and the extent to which black stilts move between areas is useful for management purposes. For example, such knowledge enables the number of black stilts potentially affected by wetland enhancement, lake level fluctuations, and rabbit or predator control operations to be estimated. Black Stilt Recovery Programme staff appear to have a good 'feel' for the current distribution and movements of black stilts, based on their extensive experience of the population, and on records of black stilt sightings since 1982. However, a quantitative, objective analysis of the distribution of black stilts in the Upper Waitaki Basin is desirable for at least four reasons. Such an analysis would 1) make efficient use of all black stilt sightings recorded by DOC; 2) be permanent; 3) be easily repeated and updated as more sightings are recorded, and 4) facilitate further quantitative analyses of the distribution of black stilts.

In this Appendix I define the geographic ranges of three 'sub-populations' of black stilts, based on cluster analysis of the 11 areas defined by DOC. I also present a breakdown of the size of these sub-populations from 1985 to 1992.

Cluster analysis is used to group one set of variables on the basis of a second set of variables that characterises the first set. I used cluster analysis to group the 11 areas recognised by DOC, on the basis of recorded sightings of colour-banded black stilts in the Upper Waitaki River Basin. At the time of this analysis (April 1994), 2743 sightings of 150 black stilts were recorded in the black stilt database at DOC's Twizel Field Centre. These sightings were made between September 1982 and April 1994. Table A2.2 lists the total number of times each band combination was sighted in each area. The statistal package 'Statistica' (StatSoft Incorporated 1994) was used to perform cluster analysis on a matrix of Jaccard's coefficient of dissimmilarity between areas. Areas were grouped using the Unweighted Paired Groups Method of Arithmetic Averages (UPGMA). Thus, the geographic range of each sub-population was defined in terms of the 11 areas recognized by DOC.

The results of the cluster analysis are presented in Figure A2.1 as a dendrogram. I recognised three geographic sub-populations on the basis of three clusters of areas:

Sub-population A ('Pukaki/Tekapo'): Tasman, Godley, Cass, Tekapo and Pukaki;
Sub-population B ('Benmore'): Ohau, Homestead, Ahuriri, Tekapo River;
Sub-population C ('Hopkins'): Hopkins.

The Forks area formed a separate cluster of one. However, I did not define this cluster as a distinct sub-population, because it was based on only two sightings of one colour banded black stilt. In other areas between 11 and 891 sightings of colour-banded black stilts had been made (Table A2.2).

The sightings records indicate that most black stilts spent most of their lives within one geograhic sub-population range (Table A2.2). Thus, the geographic ranges of sub-populations appear to have been stable, at least between 1982 and 1994.

The sizes of the three sub-populations, and the entire Upper Waitaki Basin population, between 1985 and 1992, are shown in Table A2.3. Sub-population size was determined by adding the number of colour banded and unbanded black or dark hybrid (Node F and darker) stilts that were sighted within the geographic range of each sub-population. In each calendar year, any given individual black stilt was considered to be a member of a sub-population if it was sighted within the defined geographic range of that sub-population. Thus, black stilts were occasionally considered to be members of more than one sub-population. The numbers of unbanded black stilts reported in each area were taken from unpublished Department of Conservation reports of annual winter counts. These reports are held at the Twizel Field Centre.

Sub-population sizes were remarkably constant. Between 1982 and 1992, sub-population A comprised 32 to 48 percent of the annual total Upper Waitaki Basin population. The equivalent range for sub-population B was 50 - 66 %; for sub-population C it was 2 - 7.6 % (Table A2.3).

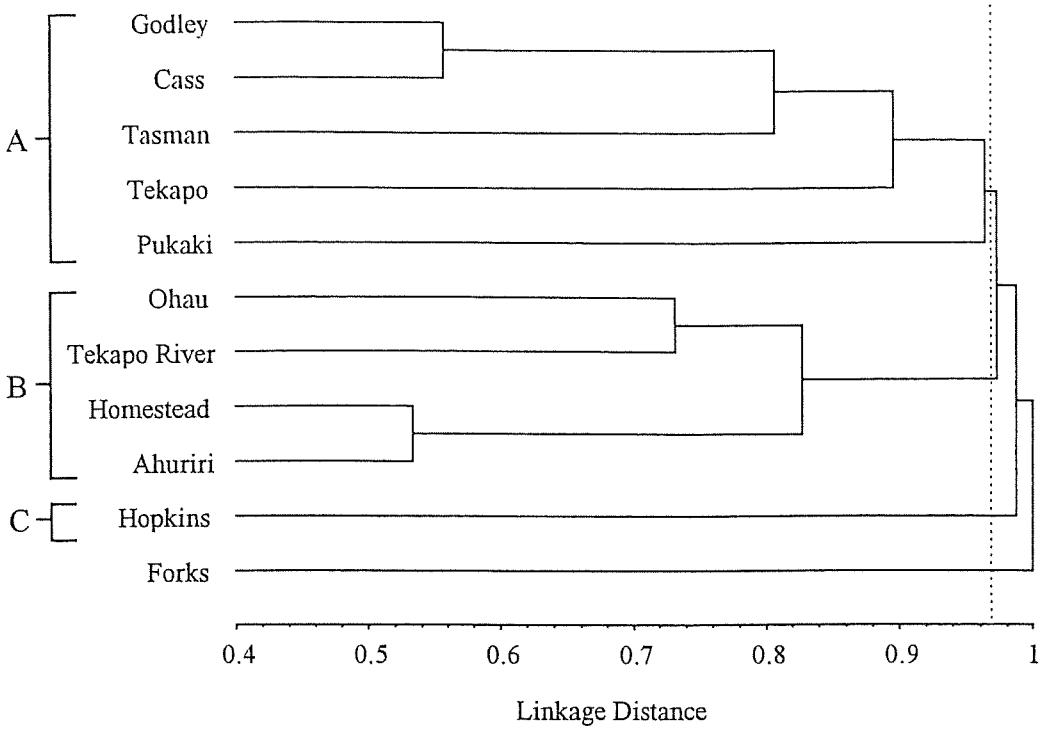


Figure A2.1. Dendrogram showing the grouping of 11 areas into three geographic sub-populations, A, B and C. The dashed line shows the linkage distance at which sub-populations were distinguished.

Table A2.1. Eleven areas as defined for DOC black stilt databases.

Area	Wetlands within each area		
AHURIRI	SH8 to lake	Above gorge	Gorge to SH8
	Birchwood Ponds	Ben Avon Ponds	East Branch
	Henburn Junction Wetland	Tara Hills Ponds	Ben Omar Swamp
	Willowburn Swamp	Ahuriri Delta	
TASMAN	Tasman River	Tasman Delta	Glenntanner Swamp
	Jollie River	Stilt Pond	Glenntanner Stream
	Dead Horse Creek Pond		
OHAU	Lower Ohau River	Upper Ohau River	Ruataniwha Springs
	Aviary Ponds	Kevins Diversion	Airport Swamp
	Aubrey's Irrigated Paddocks	Twizel River	Lake Poaka
	Ben Ohau Wetlands	Lake Merino	Dry Stream Swamp
HOMESTEAD	McAughtrie's Swamp	Big Tarn	Ohau Road Tarns
	Shelton Downs Ponds	Swan Lagoon	Homestead Tarn
	Benmore Station Swamp		
HOPKINS	Hopkins River	Dobson River	Hopkins Delta
	Glen Lyon Swamp	Glen Mary Swamp	Temple Stream
GODLEY	Godley River	Godley Delta	Mt Gerald Wetlands
	MaCauley Wetland	MaCauley River	Centre Stream
	Sibbald Island		
CASS	Cass River	Cass Delta	Waterfall Stream
	Joseph Swamp	Mick's Lagoon	Mailbox Inlet
	Clover Hill Ponds	Corner Pond	Stoney Tarn
	Glenmore Deer Paddocks		
TEKAPO	McGregor Causeway	Lake MacGregor	South East Bay
	Jimmy's Lagoon	Lake Shore	Mt Hay Tarns
TEKAPO RIVER	Above Gorge	Below Iron Bridge	Pukaki River
	Gorge to Iron Bridge	Tekapo Delta	
PUKAKI	Lake shore	Spillway Pond	Tasman Downs
FORKS	Balmoral Camp Tarns	Army Tarns	Forks River

Table A2.2. Department of Conservation records of black stilt sightings in the Upper Waitaki River Basin between September 1982 and April 1994. Colour banded black stilts have one or two bands on either or both legs. The bands are listed here in this order: Top left, bottom left, top right, bottom right. b = blue; bk = black; g = green; m = metal; r = red; w = white; y = yellow; x = no band. Thus, bxgx indicates a bird with a blue band on its left leg and a green band on its right leg. Common alternative ways of representing this bird include: B/G, b/g, B - G and b - g. The same band combination has occasionally been reused after a bird has died. This is indicated by a '2' after the band combination. *e.g.* g2xxx.

Sub-populations:		A	A	A	A	A	B	B	B	B	C		
	Bands	Godley	Cass	Tekapo	Tasman	Pukaki	Ohau	Tekapo River	Homestead Area	Ahuriri	Hopkins	Forks	Total
1	bbxx	0	0	0	0	0	0	0	41	37	0	0	78
2	bbyx	0	1	0	0	0	0	0	0	0	0	0	1
3	bgyx	0	0	0	0	0	0	0	0	2	0	0	2
4	bmby	10	3	0	7	0	1	0	4	77	0	0	102
5	brgx	0	8	0	0	0	0	0	0	0	0	0	8
6	brwx	0	0	0	0	0	23	0	0	0	0	0	23
7	brxx	5	9	1	0	0	0	0	0	0	0	0	15
8	bwgx	0	0	0	0	0	19	1	3	3	0	0	26
9	bwwx	0	0	0	0	0	3	0	0	0	3	0	6
10	bwxx	0	0	0	1	0	0	0	0	0	0	0	1
11	bwxx	0	0	0	0	0	0	0	14	17	0	0	31
12	bxgx	0	0	0	13	0	0	0	0	0	0	0	13
13	bxmx	0	1	0	0	0	0	0	0	0	0	0	1
14	bxxx	10	9	4	31	0	1	0	0	0	0	0	55
15	bygx	0	0	0	0	0	0	0	0	2	1	0	3
16	byxx	5	10	14	1	0	0	0	0	0	0	0	30
17	byym	1	0	0	0	0	0	0	0	0	0	0	1
18	byyx	0	0	0	0	0	0	0	3	26	0	0	29
19	g2xxx	0	0	0	0	1	0	0	0	0	0	0	1
20	gbrx	1	17	0	0	0	0	0	0	0	0	0	18
21	gbwx	9	6	0	0	0	0	0	0	0	0	0	15
22	ggrx	0	0	0	1	0	0	0	0	0	0	0	1
23	ggwx	0	0	0	0	0	2	0	2	39	0	0	43
24	ggxx	0	4	0	25	0	0	0	0	0	0	0	29
25	ggyw	0	0	0	0	0	4	0	0	0	0	0	4
26	grgx	0	0	0	0	0	0	0	0	18	0	0	18
27	grrx	1	8	0	10	0	0	0	0	0	0	0	19
28	grwx	11	15	0	2	0	10	1	0	1	0	0	40
29	grxx	0	0	0	0	0	99	7	0	2	0	0	108
30	gryx	0	0	0	0	0	0	0	0	0	4	0	4
31	gwbm	0	3	0	0	0	0	0	0	0	0	0	3
32	gwgx	0	0	0	0	0	0	0	0	12	0	0	12
33	gwrx	9	10	4	0	0	0	0	0	0	0	0	23
34	gwwx	2	0	0	0	0	0	0	0	0	0	0	2
35	gwxx	0	25	0	54	0	0	0	0	0	0	0	79
36	gwyx	10	1	0	0	0	0	0	0	0	0	0	11
37	gxgx	0	8	0	0	0	0	0	0	0	0	0	8
38	gxwx	0	0	0	0	0	32	0	18	5	0	0	55
39	gxxx	0	0	0	0	0	0	0	13	8	0	0	21
40	gybm	0	3	0	0	0	0	0	0	0	0	0	3
41	gyrx	0	0	0	1	0	0	0	0	0	0	0	1
42	gyxx	2	3	0	9	0	0	0	0	0	0	0	14
43	gyyx	0	2	0	6	3	0	0	0	0	0	0	11
44	mxb2x	0	0	0	0	0	1	0	0	0	0	0	1
45	mxbg	0	0	0	0	0	0	0	4	0	0	0	4
46	mxbry	0	1	0	0	0	0	0	0	0	0	0	1
47	mxbw	0	0	0	0	0	87	9	21	6	0	0	123
48	mxby	0	0	0	0	0	1	0	0	0	0	0	1
49	mxgb	0	0	0	0	0	1	0	18	20	0	0	39
50	mxgr	0	0	0	0	0	0	0	5	0	0	0	5
51	mxgw	0	1	0	0	0	0	0	0	0	0	0	1
52	mxgx	0	0	0	0	0	19	1	19	0	0	0	39
53	mxgy	0	0	0	0	0	1	0	0	0	0	0	1
54	mxgy2	0	0	0	0	0	0	0	4	6	0	0	10
55	mxrg	0	0	0	0	0	1	0	0	0	0	0	1
56	mxry	0	0	0	0	0	4	0	0	0	0	0	4

Sub-populations:		A	A	A	A	A	B	B	B	B	C		
	Bands	Godley	Cass	Tekapo	Tasman	Pukaki	Ohau	Tekapo River	Homestead Area	Ahuriri	Hopkins	Forks	Total
57	mxwb	0	0	0	0	0	1	0	0	0	0	0	1
58	mxwx	0	0	0	0	0	1	0	0	0	0	0	1
59	mxwy	7	54	0	0	0	0	0	0	0	0	0	61
60	mxy3x	0	2	0	0	0	0	0	0	0	0	0	2
61	mxyb	0	0	0	0	0	0	0	1	0	0	0	1
62	mxyr	0	0	0	0	0	0	0	1	0	0	0	1
63	mxyw	0	0	0	0	0	0	0	0	2	0	0	2
64	mygrb	0	3	0	0	0	0	0	0	0	0	0	3
65	myrx	0	0	0	3	0	0	0	0	0	0	0	3
66	myry	0	1	0	0	0	0	0	0	0	0	0	1
67	rbwx	0	0	0	0	0	14	0	1	1	0	0	16
68	rbxx	2	0	0	0	0	0	0	0	0	0	0	2
69	rbyx	0	0	0	0	0	0	0	4	17	0	0	21
70	rgwx	4	9	0	0	0	0	0	0	0	0	0	13
71	rgxx	0	0	0	0	0	9	1	0	0	0	0	10
72	rgyx	0	0	0	0	0	0	0	0	4	0	0	4
73	rrwx	0	0	0	0	2	5	0	0	0	0	0	7
74	rrxx	0	0	0	0	0	23	0	0	0	0	0	23
75	rwxx	0	0	0	0	0	21	5	0	0	0	0	26
76	rwyx	0	0	0	0	0	2	0	0	0	0	0	2
77	rxmx	0	1	0	0	0	0	0	0	0	0	0	1
78	rxwx	0	0	0	0	0	6	0	0	0	0	0	6
79	rxxx	26	13	0	0	0	0	0	0	0	0	0	39
80	rygx	0	0	0	0	0	0	0	1	4	0	0	5
81	rywx	0	0	0	0	0	0	0	0	1	0	0	1
82	ryyx	0	0	0	0	0	8	0	1	0	0	0	9
83	wbg2x	0	0	0	0	0	2	2	0	0	0	0	4
84	wbgx	0	0	0	0	0	3	0	2	0	0	0	5
85	wbwx	0	0	0	0	0	0	0	0	2	0	0	2
86	wbxx	0	0	0	0	0	12	0	34	15	0	0	61
87	wbyx	0	4	0	0	0	0	0	0	0	0	0	4
88	wgrx	0	0	0	0	0	0	0	2	30	0	0	32
89	wgwx	0	0	0	0	0	2	0	2	1	0	0	5
90	wgxx	0	0	0	0	0	1	0	0	0	0	0	1
91	wrrx	0	0	0	0	0	0	0	0	1	0	0	1
92	wrwx	0	0	0	0	0	97	2	0	0	0	0	99
93	wrxx	0	0	0	0	0	3	0	0	0	0	0	3
94	wryx	0	1	0	4	0	0	0	0	0	0	0	5
95	wwgx	0	0	0	0	4	3	0	2	0	0	0	9
96	wwrr	0	0	0	0	0	0	0	0	0	0	2	2
97	wwrw	0	0	0	0	0	0	0	4	0	0	0	4
98	wwry	0	0	0	6	0	0	0	0	0	0	0	6
99	wwwr	0	0	0	5	0	0	0	0	0	0	0	5
100	wwwx	0	1	0	0	0	0	0	19	34	0	0	54
101	wwwy	0	0	0	0	0	7	0	0	0	0	0	7
102	wwxx	0	0	0	0	0	1	0	0	0	0	0	1
103	wwyg	0	0	0	0	0	0	0	0	2	0	0	2
104	wwyr	0	0	0	0	0	0	0	0	1	1	0	2
105	wwyx	9	16	0	0	0	1	0	0	0	0	0	26
106	wwyy	0	0	0	0	0	0	0	1	0	0	0	1
107	wxwx	0	1	0	48	0	0	0	1	0	0	0	50
108	wxxx	0	0	0	35	1	0	0	0	0	0	0	36
109	wygx	0	0	0	0	0	35	4	18	0	0	0	57
110	wyrg	0	0	0	0	0	1	0	0	0	0	0	1
111	wyrx	0	0	0	0	0	0	0	2	7	0	0	9
112	wywx	0	0	0	0	0	1	0	9	2	0	0	12
113	wyxx	0	0	0	0	0	0	0	52	32	0	0	84
114	wyyw	0	1	0	0	0	0	0	0	0	0	0	1
115	wyyx	0	0	0	0	0	1	0	1	0	0	0	2
116	xxg	1	0	0	0	0	61	1	1	1	0	0	65
117	xxgr	2	1	0	0	0	0	0	0	0	0	0	3
118	xxwbk	0	0	0	0	0	33	5	0	0	0	0	38
119	xxwr	0	0	0	0	0	2	0	0	0	0	0	2
120	xxwy	0	0	0	0	0	11	0	0	0	0	0	11
121	yb2xx	0	0	0	0	0	8	0	0	0	0	0	8
122	ybrx	0	0	0	0	0	1	0	0	0	0	0	1
123	ybwx	0	0	0	0	0	0	0	7	22	0	0	29
124	ybxx	0	0	0	0	0	0	0	14	7	0	0	21
125	ybyx	2	2	0	0	0	0	0	0	0	0	0	4
126	yggx	0	0	0	0	0	2	0	0	0	0	0	2
127	ygrx	0	0	0	0	0	3	5	2	0	0	0	10
128	ygwx	0	0	0	28	0	0	0	2	2	0	0	32
129	ygxx	0	0	0	0	0	124	5	23	2	0	0	154
130	ygyx	3	11	0	1	0	0	0	0	0	0	0	15

Sub-populations:		A	A	A	A	A	B	B	B	B	C		
	Bands	Godley	Cass	Tekapo	Tasman	Pukaki	Ohau	Tekapo River	Homestead Area	Ahuriri	Hopkins	Forks	Total
131	ymbg	1	1	0	0	0	0	0	0	0	0	0	2
132	ymgx	1	1	0	0	0	0	0	0	0	0	0	2
133	ymyg	0	2	0	0	0	0	0	0	0	0	0	2
134	yrrx	0	0	0	0	0	20	0	1	0	0	0	21
135	yrwx	0	0	0	0	0	0	0	0	0	1	0	1
136	yrxx	0	0	0	0	0	0	0	18	54	0	0	72
137	yrym	0	2	0	0	0	0	0	0	0	0	0	2
138	ywrx	0	0	0	0	0	1	1	0	0	0	0	2
139	ywwx	0	0	0	8	0	0	0	0	0	0	0	8
140	ywwy	0	1	0	0	0	0	0	0	0	0	0	1
141	ywxx	0	0	0	0	0	1	0	9	0	0	0	10
142	yxgx	0	2	0	8	0	0	0	0	0	1	0	11
143	yxmx	0	2	0	0	0	0	0	0	0	0	0	2
144	yxrx	0	0	0	0	0	55	0	5	0	0	0	60
145	yxxx	34	16	0	0	4	0	0	0	0	0	0	54
146	yygx	0	0	0	0	0	0	0	0	14	0	0	14
147	yyrx	0	0	0	0	0	0	0	0	1	0	0	1
148	yyxx	0	0	0	0	0	0	0	2	10	0	0	12
149	yyym	1	1	0	0	0	0	0	0	0	0	0	2
150	yyyx	5	12	0	0	0	0	0	0	0	0	0	17
	TOTAL	174	309	23	307	15	891	50	411	550	11	2	2743

Table A2.3. Size of the three sub-populations (Totals in A, B and C) defined on the basis of cluster analysis. Note that a comprehensive record of banded black stilts sighted in 1993 was not available when this analysis was undertaken. The size of each sub-population is also shown as a percentage of the total number of black stilts sighted in the Upper Waitaki Basin each year (% Total). Individual black stilts were occasionally sighted within the geographic range of more than one sub-population. Therefore, the totals of sub-populations do not add to the total of the entire Upper Waitaki Population in all years. Years for which records of numbers were incomplete (as at April 1994) are indicated by - .

	Entire Upper Waitaki Basin Population			Sub-population A (Pukaki/Tekapo)			
	Banded	UB	Total	Banded	UB	Total in A	% Total
1984	16	-	-	6	-	-	-
1985	22	47	69	8	14	22	32
1986	29	43	72	14	19	33	46
1987	41	40	81	16	19	35	43
1988	49	38	87	21	13	34	39
1989	67	33	100	25	12	37	37
1990	71	30	101	26	10	36	36
1991	71	29	100	30	10	40	40
1992	61	18	79	32	6	38	48
1993	-	16	-	24	6	30	-
1994	-	12	-	-	6	-	-

	Sub-population B (Benmore)				Sub-population C (Hopkins)			
	Banded	UB	Total in B	% Total	Banded	UB	Total in C	% Total
1984	9	-	-	-	0	-	-	-
1985	12	31	43	62	0	2	2	2.9
1986	16	20	36	50	0	4	4	5.6
1987	26	19	45	56	0	2	2	2.5
1988	28	22	50	57	2	3	5	5.7
1989	41	19	60	60	2	2	4	4.0
1990	34	18	52	51	0	2	2	2.0
1991	41	17	58	58	1	2	3	3.0
1992	42	10	52	66	4	2	6	7.6
1993	57	9	66	-	2	1	3	-
1994	-	5	-	-	-	1	-	-

APPPENDIX 3

Definitions of black stilt behaviours

Table A3.1. Black stilt behaviours as defined for the purposes of this thesis. Note that these categories are not necessarily mututally exclusive. For examples of other definitions of stilt (*Himantopus* spp.) behaviour see Hamilton (1975), Goriup (1982), Pierce (1985), Reed (1986), Adams (1995), and Hume (1995).

A. EVENTS		
Behaviour	Code	Description
Peck		• Includes Pierce's (1985) pecking, plunging, snatching, probing, lateral probing, scything. (I did not observe black stilts use Pierce's (1985) filtering, raking, or bill pursuit foraging methods.) • Count repeated probes and lateral probes in the same spot as one 'peck'. Only consider probes separate if the bird lifts its bill out of the water or substratum and/or takes a step between probing action. • Count each scythe as one 'peck'. Black stilts almost always step between each scythe. Note that I observed very little scything behaviour by black stilts on lake deltas in winter. • For other types of 'pecks', the stilt thrusts its head rapidly forward toward its (presumed) prey on or in the water, then pulls its head back quickly. Head movements that were not 'carried through' were not defined as pecks. Often, but not always, the bill did not contact the water surface during these aborted pecks.
Step		• Lift a leg and place it down again. May be forward, backward or 'on the spot'. Sometimes legs are not visible but the bird is moving, *e.g.* when the bird is in deep water or partly obscured by a bank or vegetation. In these circumstances, count each forward jerk of the head that accompanies each step.
Defecate	DEF	• Defecates.

Table A3.1 continued.

B. STATES OR BOUTS

Behaviour	Code	Description
Foraging	FOR	• Bouts of feeding behaviour. Discriminated from walking or running by frequent changes in direction. Almost always, but not necessarily, in water or on wet substratum.
Fishing	FIS	• Walking slowly in water with the head held high and sometimes tilted to one side. Fewer changes in direction than when foraging, but more than when walking. Very low pecking rate, but when an (apparent) attempt to capture fish is made, the stilt may chase the fish and peck rapidly. Often the stilt pecks at the water between its own legs and turns very frequently and quickly during the 'chase'. Succesful attacks distinguished by distinctive swallowing action and sometimes by the sight of the fish. This behaviour is often interspersed with ordinary foraging.
Standing	STA	• Both legs on the ground, head not tucked in.
Roosting	ROO	• Head tucked in close to body or under wing. Usually standing on one leg but sometimes sitting.
Sitting	SIT	• Sitting on the ground, head not tucked in.
Preening	PRE	• Running bill through feathers. Can be used in conjunction with standing or sitting.
Walking	WAL	• Walking without frequent changes in direction. May occasionally perform a feeding behaviour.
Running	RUN	• Running. As for walking but faster.
Soliciting	SOL	• One bird (presumably the female) stretches neck forward, and down close to the water surface and rapidly moves its bill horizontally left and right in the water.
Copulating	COP	• One bird mounts the other.
Mating	MAT	• Mating behaviour other than soliciting or copulating, as described by Pierce (1982a).
Flying	FLY	• Flying.
Nest building	NES	• Picking up debris and throwing it together on the ground.
Yapping	YAP	• Frequent vocalisations.
Head bobbing	BOB	• Frequent up and down movements of the head, usually with the head tilted to one side.
Comfort movements	COM	• Stretching wings, ruffling feathers,

APPENDIX 4

Invertebrate sampling method

To undertake the research reported in this thesis, I needed to quantify aquatic macro-invertebrates in the wide range of substrata, water depths and current velocities that occur on lake deltas, at black stilt nest sites and in artificial ponds. Substrata in both lentic and lotic habitats included mud, silt, sand, gravel and cobbles, and water depths ranged from 0 cm (*i.e.* surface water only) to *c.* 20 cm. Some sampling sites included aquatic macrophytes, emergent or submerged terrestrial vegetation, thick detritus, or, in the artificial ponds (Chapter 8), barley straw. Furthermore, invertebrate densities were highly variable. A sampling method was required that would effectively sample invertebrates on the substrate and in the water column in these diverse conditions. Here I describe the testing and development of the sampling method used in this study.

Samples were taken by placing a 0.1 m^2 stainless steel cylinder in the substrate and rotating it so that it cut 5 cm into the substrate. The bottom edge of the cylinder cut through most straw, detritus and vegetation. A sieve (0.8 mm mesh, 200 mm diameter, 50 mm deep) was passed quickly and repeatedly through the water within the cylinder using one hand, while the water and substratum were stirred vigorously with the other hand. The sieve was emptied every few seconds into a bucket attached to the outside of the cylinder. Detritus and vegetation, and soft or loose substrate to a maximum depth of 5 cm (approximate depth to which black stilts probe) were also removed and placed in the bucket. Gradations on the bucket allowed a double check of the volume of substrate removed; 0.1 m^2 to 5 cm depth yields 5 litres.

Initially, it seemed desirable to standardise the sampling effort by sieving for a set period of time. To determine the optimum sieving period, samples were taken at four sites that varied in invertebrate densities, substrata, water depths, current velocities and amount of vegetation. At each site, the water and substrata within the cylinder was sieved and removed as above, except that a separate bucket was used for each consecutive 30 seconds of sieving. Thus, the yield of the sampling method could be plotted through time, as in Figures A4.1 and A4.2. At most sites, most invertebrates within the area delimited by the cylinder were collected in the first 2 minutes of sampling. However, at muddy sites (such as the Ahuriri and Tasman Deltas in these trials) sampling was impeded because the sieve easily became clogged. Thus, time spent sieving was not the best way to standardise sampling effort.

After further tests, it was apparent that the most complete collection of all macro-invertebrates within the cylinder would be obtained by sieving until no invertebrates were visible within the cylinder, or in the sieve, for three consecutive passes with the sieve. At sites with coarse substrata and no detritus, this would take less than 5 minutes, whereas sites with much mud or detritus sampling would take up to 15 minutes. This method was used for all samples taken in this study, except for those taken for the small-scale substrate addition experiment (Chapter 7), which had been completed before the above method had been developed. The method used in the small-scale experiment is described in Chapter 7.

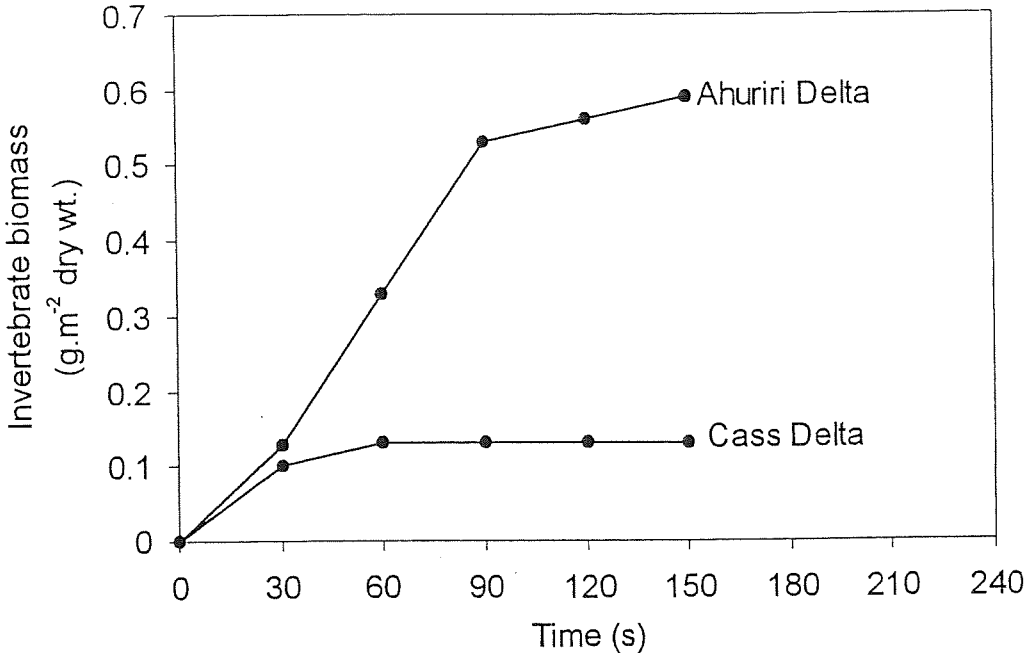


Figure A4.1. Cumulative invertebrate biomass sampled over 150 s at sites with low invertebrate densities and biomass.

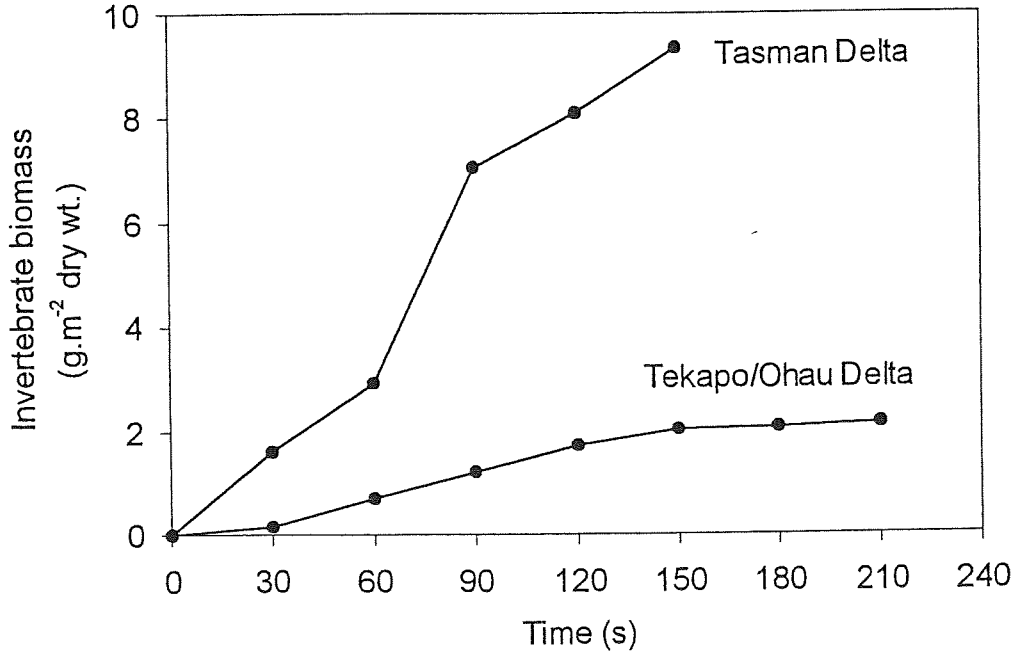


Figure A4.2. Cumulative invertebrate biomass sampled over 150 s - 210 s at sites with high invertebrate densities and biomass.

APPENDIX 5

Percentage of time spent foraging on lake deltas

At the same time as I measured feeding and searching rates of black stilts on lake deltas (Chapter 3), I estimated the percentage of time that black stilts spent foraging (%TIME). Between each 30 second focal animal observation (see Chapter 3 for details), I scanned all black stilts at each foraging site, and recorded whether they were foraging. I was able to keep track of individuals because most black stilts were colour banded, and usually only 2 - 4 were present at a foraging site. I had originally intended to test whether %TIME was related to lake level. However, my measurements of %TIME showed a high level of variation and no relationships with lake levels were evident. The data were variable because the periods of time during which I observed black stilts (20 - 90 minutes) were short compared to the duration of most foraging or brooding bouts (typically 20 - 60 minutes). Thus, %TIME ranged from 0 - 100 at many sites. Nevertheless, these measurements add to our knowledge of the behaviour of black stilts on lake deltas, and are summarised below.

My observations of black stilts were restricted to periods shorter than 90 minutes during daylight (*c.* 0800 - 1730 h) between 1 March and 31 August (autumn/winter). Observations during these periods suggest that black stilts on all lake deltas spent most of their time foraging (Table A5.1). Many observers (*e.g.* Pierce 1985, 1986; S. Elkington and D. Murray, pers. comm.) have noted that black stilts often roost during the middle of the day. My observations support this view; black stilts observed during the middle of the day were more likely to be roosting than those observed in the morning or late afternoon (Fig. A5.1).

Table A5.1. Percentage of time black stilts spent foraging (%TIME) on six lake deltas, based on pooled data from each delta.

Delta	Minutes foraging	Minutes observed	% Time spent foraging
Ahuriri	412	511	81
Cass	182	237	71
Godley	1468.2	1524.6	96
Hopkins	459	499	92
Tasman	2888.5	3583	81
Tekapo/Ohau	504.5	673	75
Total	5914.2	7027.6	84

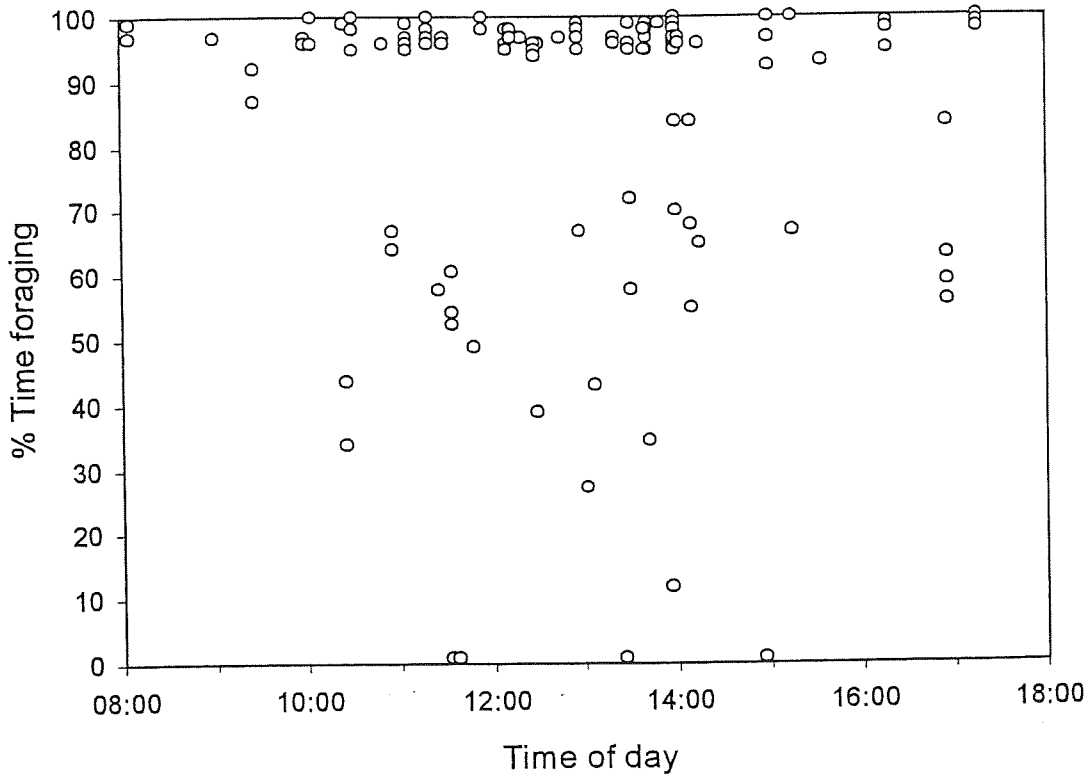


Figure A5.1. Percentage of time black stilts spent foraging during daylight, autumn and winter (1 March - 31 August, 1992 - 1994). Data for all deltas are pooled. Each point represents an observation of one black stilt (N = 130).

APPENDIX 6

Lake delta invertebrate data

Table A6.1. (Begins on next page). Mean numbers of various invertebrate taxa in samples taken from black stilt foraging sites on lake deltas (see Chapter 3 for details). Each column represents one foraging site. N = number of samples taken at each site. Sites are identified by one or two letters that represent the delta (T = Tasman, G = Godley, C = Cass, H = Hopkins, TO == Tekapo/Ohau, and A = Ahuriri), and a number.

Site	T1	T2A	T2B	T3	T4	T5	T6	T7	T8	T23	T22	T24	T25	T26	T27	T28
N	3	3	3	5	5	5	5	5	5	5	5	5	5	5	5	5
OLIGOCHAETA	0	0	0	3.4	2.4	2	0	4	8	0	0.4	20.4	5.4	18.2	1.8	3.8
DIPTERA																
Chironomidae	0	0	0	15	0.8	1	0	0	12	0	6.6	24.6	30.6	1.8	16	23
Tanypodinae	0	0	0	0	0.4	0	0	2	0	0	1.8	0.4	0	0	0	0
Ceratopogonidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.2	0
Tipulidae sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Paralimnophila skusei	0	0	0	0	0	0	0	0	0	0	1.2	0	0	0.6	0.4	0
Aphrophila neozelandica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
?Molophilus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Limonia nigrescens	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0
Eriopterini	0	0	0	0	0	0	0	0	0	0	1.4	0	0	0	1.2	0
Hexatomini	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Austrosimulium sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Muscidae	0	0	0	0	0	0	0	0	0	0	0.4	0	0.4	3.2	1.2	0.2
Stratiomyidae	0	0	0	0	0	0	0	0	0	0	0.4	0.8	3.2	0.6	0.8	0
Tanyderidae sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tanyderidae sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sciomyzidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.2	0
Diptera pupa sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diptera larva sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diptera larva sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diptera larva sp. 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diptera unident.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diptera larva sp. 5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
COLEOPTERA																
Berosus	0	0	0	0	0	0	0	0	0	0	1.6	2.8	0.2	0.4	0.4	0
Elmidae	0	0	0	3.4	0	0	0	0	0	0	1.4	0	0	0.2	0.2	0
Antiporus strigosulus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.2	0
HEMIPTERA																
Sigara sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TRICHOPTERA																
Aoteapsyche colonica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.4	0
Paroxyethira hendersoni	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxyethira albiceps	0	0	0	0.2	0	0	0	0	0	0	5.4	0	0	0	20	0.2
Hydrobiosidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrobiosis unidentified	0	0	0	0	0	0	0	0	0	0	2.2	0	0	0.2	0.4	0
Hydrobiosis sp. A	0	0	0	0	0	0	0	0	0	0	2	0	0	3	0.4	0
Hydrobiosis umbripennis	0	0	0	0	0	0	0	0	0	0	1.2	0	0	0	0	0
Hydrobiosis parumbripennis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrobiosis harpidiosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.2	0
Psilochorema sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Psilochorema folioharpax	0	0	0	0	0	0	0	0	0	0	0.2	0	0	1.4	0	0
Psilochorema nemorale	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.2	0
Neurochorema confusum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Plectronemia mclachlani	0	0	0	0	0	0	0	0	0	0	0	0	0	0.2	0	0
Conoesucidae pupa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pycnocentrodes sp.	0	0	0	0	0	0	0	0	0	0	3.6	0	0	3.2	3.4	0
Beraeoptera roria	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oecetis unicolor	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.6
Hudsonema amabilis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.4	0.4
EPHEMEROPTERA																
Deleatidium spp.	0	0	0	0	0	0	0	0	0	0	10.8	1	0	3.4	82	0.2
PLECOPTERA																
Zelandobius confusus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32	0
Zelandobius sp.	0	0	0	0.8	0	0	0	0	0	0	0	0	0	0	0	0
Zelandobius furcillatus	0	0	0	0	0	0	0	0	0	0	3.4	0	0	0	0	0
MOLLUSCA																
Potamopyrgus antipodarum	0	0	0	0	0	0	0	0	0	0	0.6	0	0	9.2	0.6	0
Physa acuta	0	0	0	0	0	0	0	0	0	0	0	0	2.6	0.2	0	0
Lymnaea tomentosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lymnaea stagnalis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gyraulus corinna	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sphaerium novaezelandiae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ACARI	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.2	0
AMPHIPODA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HIRUDINEA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Site	T30	T31	T32	T33	T34	T37	T39	T40	T44	T45	T46	G1	G2	G21
N	5	5	5	5	5	5	5	5	5	5	5	5	5	5
OLIGOCHAETA	264	1.8	1.6	0	4	490	0	156.4	3.2	1.4	1.4	10	206	3.2
DIPTERA														
Chironomidae	51	9.4	10	7.2	1.2	328	84.8	320.8	8.4	44.4	6.2	0	10	142
Tanypodinae	0.6	0	0.8	0	0	9	0.8	5.4	3.8	0.6	0.2	0	2	0
Ceratopogonidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tipulidae sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Paralimnophila skusei	0	0	0	0	0.2	0	0	0	0	0	0	0	0	0
Aphrophila neozelandica	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0
?Molophilus	0	0	0	0	0	0	0	0	0.4	0	0	0	0	0
Limonia nigrescens	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Eriopterini	0	0	2.2	0	0	0	0.6	0	3.6	0	0.6	0	14	0
Hexatomini	0	0	0	0	0	0	0.2	0	0.2	0	0	0	0	0
Austrosimulium sp.	0	0	0.8	0	0	0	0.2	0	0	0	0	0	0	0
Muscidae	0.2	0	0	0.2	0	0.2	0	0	0.8	0	0.4	0	0	0
Stratiomyidae	0.4	0	0	0	0	0.2	0	0	0	0	0.2	0	0	0.2
Tanyderidae sp. 1	0	0	0	0	0	0	0.2	0	0	0	0	0	0	0
Tanyderidae sp. 2	0	0	0	0	0	0	0.2	0	0	0	0	0	0	0
Sciomyzidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diptera pupa sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diptera larva sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diptera larva sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diptera larva sp. 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diptera unident.	0	0	0	0	0	0	0	0	0	0	0.4	0	0	0
Diptera larva sp. 5	0	0	0	0	0	0	0	0	0	0	0	0	2	0
COLEOPTERA														
Berosus	0	0	0	0	0	0	0	0	0	0	0	0	2	0
Elmidae	3.8	0	1.4	0	0.4	0	0.2	0	0.6	0	0	0	8	0
Antiporus strigosulus	0	0	0	0	0	0	0	0.4	0	0	0	0	0	0
HEMIPTERA														
Sigara sp.	0	0	0	0	0.2	0	0	0.2	0	0	0	0	0	0
TRICHOPTERA														
Aoteapsyche colonica	0	1.4	1	0	0	0	0	0	0	0	0	0	0	0.2
Paroxyethira hendersoni	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxyethira albiceps	1	0.2	3.6	2	0.2	1.2	0.8	0	0	0	0.4	0	0	0
Hydrobiosidae	0	0	0.2	0	0	0	0	0	0	0	0	0	0	0
Hydrobiosis unidentified	0	0.2	0	0	0	0	0	0	0	0	0	0	0	0
Hydrobiosis sp. A	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrobiosis umbripennis	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrobiosis parumbripennis	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrobiosis harpidiosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Psilochorema sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Psilochorema folioharpax	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0
Psilochorema nemorale	0.2	0	0	0	0	0	0	0	0	0	0	0	2	0
Neurochorema confusum	0	0	0	0	0	0	0	0	0	0	0	0	4	0
Plectronemia mclachlani	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Conoesucidae pupa	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pycnocentrodes sp.	0.4	0.6	0.4	0	0.6	0	0	0	0	0	0	0	0	0
Beraeoptera roria	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oecetis unicolor	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hudsonema amabilis	0.8	0	0	0	0	0	0.2	0	0	0	0	0	0	0
EPHEMEROPTERA														
Deleatidium spp.	1.6	5	32	1	1	0	0.8	0	21.2	0	63	0	2	0
PLECOPTERA														
Zelandobius confusus	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Zelandobius sp.	0	1.4	0	0	0	0	0	0	0	0	0	0	0	0
Zelandobius furcillatus	0	0	0.4	0	0	0	0.4	0	115	0	104	0	8	0
MOLLUSCA														
Potamopyrgus antipodarum	1.6	0	0	0	0	0.8	0.6	0	0	0	0	0	2	0
Physa acuta	0	0	0	0	0	0.2	0	1.4	0	0	0	0	0	0
Lymnaea tomentosa	0	0	0	0	0	0	0.2	0.4	0	0	0	0	0	0
Lymnaea stagnalis	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gyraulus corinna	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sphaerium novaezelandiae	0	0	0	0	0	0	0.2	0	0	0	0	0	4	0
ACARI	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AMPHIPODA	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HIRUDINEA	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Site	G24	G25	G26	G30	G31	G32	G33	G35	G37	G38	C23	C24	H5
N	5	5	5	5	5	5	5	5	5	5	5	5	3
OLIGOCHAETA	0.4	193.4	29	1.8	119	19.2	65.8	37.8	365.8	590	2.4	0	6
DIPTERA													
Chironomidae	0.2	0.4	115	1	26.8	29	97.4	22.2	110.8	126	1.2	0	2
Tanypodinae	0	0	1	0	0.4	3	0	0.8	0	2	0.2	0	0
Ceratopogonidae	0	0	0	0	0	0	0	0	0	0	0	0	0
Tipulidae sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0
Paralimnophila skusei	0	0	0	0	0	0	0	0	0	0	0	0	0
Aphrophila neozelandica	0	0	0	0	0	0	0	0	0	0	0	0	0
?Molophilus	0	0	0	0	0	0	0	0	0	0	0.2	0	0
Limonia nigrescens	0	0	0	0	0	0	0	0	0	0	0	0	0
Eriopterini	0.4	0.6	0.6	0.4	0	0	0	0	0	0	0	1	2
Hexatomini	0	0	0	0	0	0	0	0	0	0	0	0	0
Austrosimulium sp.	0	0	0	0	0	0	0	0	0	0	0.4	0	0
Muscidae	0.2	1.8	0	0	0	0	0	0	0	0.2	1.6	0	2
Stratiomyidae	0	0.6	0	0	0	0	0	0	0	0	0	0	0
Tanyderidae sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0
Tanyderidae sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0
Sciomyzidae	0	0.4	0	0	0	0	0	0	0	0	0	0	0
Diptera pupa sp. 1	0	0	0.2	0	0	0	0	0	0	0	0	0	0
Diptera larva sp. 1	0	0	0.4	0	0	0	0	0	0	0	0	0	0
Diptera larva sp. 2	0	0	0.4	0	0	0	0	0	0	0	0	0	0
Diptera larva sp. 3	0	0	0	0	0	0	0	0	0	0	0.2	0	8
Diptera unident.	0	0	0	0	0	0	0	0	0	0.4	0	0	0
Diptera larva sp. 5	0	0	0	0	0	0	0	0	0	0	0	0	0
COLEOPTERA													
Berosus	0	0	0.4	0	0	0	0	0	0	0	0	0	0
Elmidae	0	0.2	0	0.4	0	0	0	0	0	0.2	0	1	0
Antiporus strigosulus	0	0	0	0	0	0	0	0	0	0	0	0	0
HEMIPTERA													
Sigara sp.	0	0	0	0	3.6	0	1.6	0	0	0	0	0	0
TRICHOPTERA													
Aoteapsyche colonica	0	0.6	0	0.4	0	0	0	0	0	0	0.4	1	0
Paroxyethira hendersoni	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxyethira albiceps	0	0.4	1.8	0	0	0	0	0	0	0.2	0.8	0	0
Hydrobiosidae	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrobiosis unidentified	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrobiosis sp. A	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrobiosis umbripennis	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrobiosis parumbripennis	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrobiosis harpidiosa	0	0	0	0	0	0	0	0	0	0	0	0	0
Psilochorema sp.	0	0.2	0	0	0	0	0	0	0	0	0	0	0
Psilochorema folioharpax	0	0	0	0	0	0	0	0	0	0	0	0	0
Psilochorema nemorale	0	0	0	0	0	0	0	0	0	0	0	0	0
Neurochorema confusum	0	0	0	0	0	0	0	0	0	0	0	0	0
Plectronemia mclachlani	0	0	0	0	0	0	0	0	0	0	0	0	0
Conoesucidae pupa	0	0	0	0	0	0	0	0	0	0	0	0	0
Pycnocentrodes sp.	0	0	0	1	0	0	1.2	0	0	0	0	0	0
Beraeoptera roria	0	0	0	0	0	0	0	0	0	0	0	0	0
Oecetis unicolor	0	0	0	0	0	0	0	0	0	0	0	0	0
Hudsonema amabilis	0	0	0	0.2	0	0	0	0	0	0	0	0	0
EPHEMEROPTERA													
Deleatidium spp.	0.4	9.8	0	3.4	0	0	0	0	0	0.2	24.4	20	0
PLECOPTERA													
Zelandobius confusus	0	0	0	0	0	0	0	0	0	0	0	0	0
Zelandobius sp.	0	0	0	0	0	0	0	0	1.2	0	0	0	0
Zelandobius furcillatus	0	0	0	1	0	0	0	0	0	0.6	41.8	46	0
MOLLUSCA													
Potamopyrgus antipodarum	0.2	0	0	0.4	0	0	0	0	0	0	0	0	0
Physa acuta	0	0	0	0	3.4	0	0	0	0	0	0.2	0	0
Lymnaea tomentosa	0	2	0	0	0	0.2	0	1.2	0	0	0	0	0
Lymnaea stagnalis	0	0	0	0	0	0	0	0	0	0	0	0	0
Gyraulus corinna	0	0	0	0	0	0	0	0	0	0	0	0	0
Sphaerium novaezelandiae	0	0	0	0	0.2	0.6	5.6	0.2	0	0	0	0	0
ACARI	0	0	0	0	0	0	0	0	0	0	0	0	0
AMPHIPODA	0	0	0	0	0	0	0	0	0	0	0	0	0
HIRUDINEA	0	0	0	0	0	0	0	0	0	0	0	0	0

Site	H22	H30	A1	A4	A5	A6	A21	A22	A23	A24	TO1	TO2	TO3
N	3	3	5	5	5	5	5	5	5	5	5	5	5
OLIGOCHAETA	105.6	331	348	626	519	362	42	10.4	21.2	138	68	140	486
DIPTERA													
Chironomidae	69.2	179	258	72	121.6	215	560	0.4	8	557	60.6	111	35.8
Tanypodinae	1	4.6	0	8	5.4	2.4	0.2	0	0.4	6.2	0.4	0	4
Ceratopogonidae	0	0	0	0	0.2	0	0	0	0	0.2	0.2	0	0
Tipulidae sp. 1	0.2	0	0	0	0	0	0	0	0	0	0	0	0
Paralimnophila skusei	0	0	0	0	0	0	0	0	0	0	0	0	1
Aphrophila neozelandica	0	0	0	0	1.4	0	0	0	0	0	0	0	0
?Molophilus	0	0	0	0	0	0.4	0	0	0	0	0	0	0
Limonia nigrescens	0	0	0	0	0	0	0	0	0	0	0	0	0
Eriopterini	0	0	0	0	0	0	0	0	0	0	0	0	0
Hexatomini	0	0	0	0	0	0	0	0	0	0	0	0	0
Austrosimulium sp.	0	0	0	0	0	0	0	0	0	0.6	0	0	0
Muscidae	1.2	0	0	0	0.8	0	0	1.2	0	0.2	0	0	0
Stratiomyidae	0	0	0	0	0	0	0	0.2	0	0	0	0	0
Tanyderidae sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0
Tanyderidae sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0
Sciomyzidae	0	0	0	0	0	0	0	0	0	0	0	0	0
Diptera pupa sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0
Diptera larva sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0
Diptera larva sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0
Diptera larva sp. 3	0	0	0	0	0	0	0	0	0	0	0	0	0
Diptera unident.	0	0	0	0	0	0	0	0	0	0	0	0	0
Diptera larva sp. 5	0	0	0	0	0	0	0	0	0	0	0	0	0
COLEOPTERA													
Berosus	0	0.2	0	0	0	0	0	0	0	0	0	0	1.2
Elmidae	0	0	2	0	0.2	1	0	0.4	0	0	6.6	0	0
Antiporus strigosulus	0	0	0	0	0	0	0	0	0	0	0	0	0
HEMIPTERA													
Sigara sp.	0	0	0	0	6	0	0	0	0	0	4	0	0
TRICHOPTERA													
Aoteapsyche colonica	0	0	0	0	0	0	0	0	0	0	0	0	0
Paroxyethira hendersoni	0	0	0	6	0.4	3.2	0	0	0	0	0	0	0
Oxyethira albiceps	0.2	0	4	0	0	0	0	3	0	7	0	0	9.4
Hydrobiosidae	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrobiosis unidentified	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrobiosis sp. A	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrobiosis umbripennis	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrobiosis parumbripennis	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrobiosis harpidiosa	0	0	0	0	0	0	0	0	0	0	0	0	0
Psilochorema sp.	0	0	0	0	0	0	0	0	0	0	0	0	0
Psilochorema folioharpax	0	0	0	0	0	0	0	0	0	0	0	0	0
Psilochorema nemorale	0	0	0	0	0	0	0	0	0	0	0	0	0
Neurochorema confusum	0	0	0	0	0	0	0	0	0	0	0	0	0
Plectronemia mclachlani	0	0	0	0	0	0	0	0	0	0	0	0	0
Conoesucidae pupa	0	0	0	0	0	0	0	0	0	0	0	0	0
Pycnocentrodes sp.	0	0	0	0	0.2	0	0	0	0	0	0	0	0
Beraeoptera roria	0	0	0	0	0	0	0	0	0	0	0	0	0
Oecetis unicolor	0	0	0	2	0	0	0	0	0	0	0	0	0
Hudsonema amabilis	0.2	0	0	0	0	0	0	0	0	0.6	1.4	0	2.6
EPHEMEROPTERA													
Deleatidium spp.	0	0	0	0	0	0	0	0	0	0	0	0.2	0
PLECOPTERA													
Zelandobius confusus	0	0	0	0	0	0	0	0	0	0	0	0	0
Zelandobius sp.	0	0	0	0	0	0	0	0	0	0	0	0	0
Zelandobius furcillatus	5.6	0	0	0	0	0	0	0	0	0	0	0	0
MOLLUSCA													
Potamopyrgus antipodarum	0	0	380	186	128.4	119	42.8	1.6	0.2	12.8	0	0	0
Physa acuta	0	0	56	28	13.6	88.2	52.2	28	0.6	59.2	0	0	0.8
Lymnaea tomentosa	0	0	0	74	87.4	15	19.4	2.8	0	0	0.4	21.2	1.6
Lymnaea stagnalis	0	0	16	6	9.2	0	0.4	0.2	0	13.4	0	0	0
Gyraulus corinna	0	0.4	180	74	3.2	4.8	0	8.6	0	0	0	0	0
Sphaerium novaezelandiae	1.8	0	0	4	0	31	3.2	0	0.6	19.4	21.6	0.2	0
ACARI	0	0	0	2	0	0	0	0	0	0	0	0	0
AMPHIPODA	0	0	0	0	0	0	0	0.2	0	0	0	0	0
HIRUDINEA	0	0	0	2	0	0.2	0	0	0	0	0	0	0

Site	TO4	TO10	TO15	TO21	TO22	TO23	TO24	TO25	TO30
N	5	5	5	5	5	5	5	5	5
OLIGOCHAETA	102	55.8	133.2	378	86.4	5	14.2	53.8	5.6
DIPTERA									
Chironomidae	62	76	4.8	104	68	2.4	23.2	18.4	0
Tanypodinae	0.2	0	1	3.8	4	6	0	12.6	0
Ceratopogonidae	0	0	0	1	0	0	0	0	0
Tipulidae sp. 1	0	0	0	0	0	0	0	0	0
Paralimnophila skusei	0	0	0	0.2	0	0	0	0	0
Aphrophila neozelandica	0	0	0	0.4	0	0	0	0	0
?Molophilus	0	0	0	0	0	0	0	0	0
Limonia nigrescens	0	0	0	0	0	0	0.2	0	0
Eriopterini	0	0	0	0	0	0	0.6	0	0
Hexatomini	0	0	0	0	0	0	0	0	0
Austrosimulium sp.	0	0	0	0	0	0	4.8	0	0
Muscidae	0	0	0	0	0	0	0.6	0.6	0
Stratiomyidae	0	0	0	0	0	0	0.6	0	0
Tanyderidae sp. 1	0	0	0	0	0	0	0	0	0
Tanyderidae sp. 2	0	0	0	0	0	0	0	0	0
Sciomyzidae	0	0	0	0	0	0	0	0	0
Diptera pupa sp. 1	0	0	0	0	0	0	0	0	0
Diptera larva sp. 1	0	0	0	0	0	0	0	0	0
Diptera larva sp. 2	0	0	0	0	0	0	0	0	0
Diptera larva sp. 3	0	0	0	0	0	0	0	0	0
Diptera unident.	0	0	0	0	0	0	0	0	0
Diptera larva sp. 5	0	0	0	0	0	0	0	0	0
COLEOPTERA									
Berosus	0	0	0	0	0	0	0.6	0	0
Elmidae	0.6	0	0	0	0	31	0	0	5.8
Antiporus strigosulus	0	0	0	0	1.2	0	0	0	0
HEMIPTERA									
Sigara sp.	3.6	1.4	0	0	51.6	0	4.6	0	0
TRICHOPTERA									
Aoteapsyche colonica	0	0	0	0	0	0	0	0	0
Paroxyethira hendersoni	0.2	0	0	1.4	0	0	0	0	0
Oxyethira albiceps	0	0.2	0	0.8	0	0	0	0.4	0
Hydrobiosidae	0	0	0	0	0	0	0	0	0
Hydrobiosis unidentified	0	0	0	0	0	0	0	0	0
Hydrobiosis sp. A	0	0	0	0	0	0	0	0	0
Hydrobiosis umbripennis	0	0	0	0	0	0	0	0	0
Hydrobiosis parumbripennis	0	0	0	0	0	0	0	0	0
Hydrobiosis harpidiosa	0	0	0	0	0	0	0	0	0
Psilochorema sp.	0	0	0	0	0	0	0	0	0
Psilochorema folioharpax	0	0	0	0	0	0	0	0	0
Psilochorema nemorale	0	0	0	0	0	0	0	0	0
Neurochorema confusum	0	0	0	0	0	0	0	0	0
Plectronemia mclachlani	0	0	0	0	0	0	0	0	0
Conoesucidae pupa	0	0	0	0	0	0	0	0.2	0
Pycnocentrodes sp.	0	0	0	0	0	0	0	0	1.4
Beraeoptera roria	0	0	0	0	0	0	0	0	0
Oecetis unicolor	0	0	0	0	0	0	0	0	0
Hudsonema amabilis	0	0	0	0.2	20.8	0	0	0	0
EPHEMEROPTERA									
Deleatidium spp.	0.2	0	0	0	0	0	0	0	0
PLECOPTERA									
Zelandobius confusus	0	0	0	0	0	0	0	0	0
Zelandobius sp.	0	0	0	0	0	0	0	0	0
Zelandobius furcillatus	0	0	0	0	0	0	0	0	0
MOLLUSCA									
Potamopyrgus antipodarum	0	0	0	0	0.4	0	0	0	0
Physa acuta	2.8	0	0	4.6	12.2	0	0	0	0
Lymnaea tomentosa	5	0	0	5.4	0.4	1.6	0	0.2	0
Lymnaea stagnalis	0	0	0	0	0	0	0	0	0
Gyraulus corinna	1.2	0	0	0	0	0	0	0	0
Sphaerium novaezelandiae	0	0	4	29	0	0	0	0.2	0
ACARI	0	0	0	0	0	0	0	0	0
AMPHIPODA	0	0	0	0	0	0	0	0	0
HIRUDINEA	0	0	0	0	0	0	0	0	0

APPENDIX 7

List of invertebrates

Table A7.1. List of invertebrate taxa found in samples taken during this study. Common names are shown in parentheses. Invertebrates were identified using McFarlane (1951, 1976, 1990), Winterbourn (1973), Chapman and Lewis (1976), Stout (1976), Cowley (1978), Rowe (1987), Winterbourn and Gregson (1989), and McLellan (1993). Ephemeroptera nomenclature follows Peters and Campbell (1991).

OLIGOCHAETA (segmented worms)
- unident. spp.

HIRUDINEA (leeches)
- *Glossiphonia* sp.

INSECTA

DIPTERA (two-winged flies)
- unident. spp.
- Chironomidae (non-biting midges)
  - *Chironomus zealandicus* (bloodworms)
  - Tanypodinae: unident. sp.
- Ceratopogonidae
  - unident. sp.
- Culicidae (mosquitos)
  - *Culex* sp.
- Tipulidae (crane flies)
  - unident. spp.
  - Hexatomini: unident. spp.
  - Eriopterini: unident. spp.
  - Eriopterini: *?Molophilus* sp.
  - *Limonia nigrescens*
  - *Paralimnophila skusei*
  - *Aphrophila neozelandica*
  - *Zelandotipula* sp.
- Simuliidae (black flies or sandflies)
  - *Austrosimulium* sp.
- Muscidae
  - unident. spp.
- Stratiomyidae
  - unident. spp.
- Tanyderidae
  - *Mischoderus* sp.

DIPTERA (two-winged flies) continued.

Sciomyzidae (marsh flies)
Neolimnia sp.
Empididae (dance flies)
unident. sp.
Ephydridae (shore flies)
Ephydrella sp.
Ephydrella ?aquaria
?Brachydeutera sp.

COLEOPTERA (beetles)

Hydrophilidae
unident. sp.
Berosus sp.
Elmidae
unident. sp.
Ptilodactylidae
unident. sp.
Scirtidae
unident. sp.
Dytiscidae
Antiporus strigosulus
Liodessus plicatus
Liodessus deflectus
Homeodytes hookeri
Huxelhydrus syntheticus
Lancetes ?lanceolatus

ODONATA (damselflies and dragonflies)

Corduliidae
Procordulia grayi (yellow spotted dragonfly)
Coenagrionidae
Xanthocnemis zealandica (common redcoat damselfly or kihitara)

HEMIPTERA (bugs)

Corixidae (waterboatmen)
Sigara sp.
Notonectidae (backswimmers)
Anisops assimilis
Saldidae
Saldula sp.
Veliidae
Microvelia ?macgregori

TRICHOPTERA (caddisflies)

- Hydropyschidae
  - *Aoteapsyche colonica*
- Hydroptilidae
  - *Paroxyethira hendersoni*
  - *Paroxyethira* sp.
  - *Oxyethira albiceps*
- Hydrobiosidae
  - unident. spp.
  - *Hydrobiosis* unident. spp.
  - *Hydrobiosis umbripennis*
  - *Hydrobiosis parumbripennis*
  - *Hydrobiosis harpidiosa*
  - *Psilochorema* sp.
  - *Psilochorema folioharpax*
  - *Psilochorema nemorale*
  - *Neurochorema confusum*
- Polycentropodidae
  - *Plectrocnemia maclachlani*
  - *Polyplectropus* sp.
- Conoesucidae
  - unident. sp.
  - *Pycnocentrodes* sp.
  - *Pycnocentria* sp.
  - *Pycnocentria evecta*
  - *Olinga feredayi*
  - *Beraeoptera roria*
- Leptoceridae
  - *Oecetis unicolor*
  - *Oecetis iti*
  - *Hudsonema amabilis*
  - *Hudsonema aliena*
  - *Triplectidina oreolimnetes*
  - *Triplectides cephalotes*
- Oeconesidae
  - *Oeconesus* sp.

LEPIDOPTERA (moths)

- Pyralidae
  - *Hygraula nitens*

MEGALOPTERA (dobsonflies or 'toebiters')

- Corydalidae
  - *Archicauliodes diversus*

EPHEMEROPTERA (mayflies)

- Leptophlebiidae
  - *Deleatidium* spp.
- Coloburiscidae
  - *Coloburiscus humeralis*

PLECOPTERA (stoneflies)

Gripopterygidae
Zelandobius confusus
Zelandobius sp.
Zelandobius furcillatus
Zelandobius unicolor

MOLLUSCA

BIVALVIA (bivalves)

Sphaeriidae (pea mussels)
Sphaerium novaezelandiae

GASTROPODA (snails)

Hydrobiidae
Potamopyrgus antipodarum
Physidae
Physa acuta
Lymnaeidae
Lymnaea tomentosa
Lymnaea stagnalis
Planorbidae
Gyraulus corinna

ACARI (mites)
unident. spp.
Hydrachna maramauensis

CRUSTACEA

AMPHIPODA

unident. spp.
Paracalliope sp.
Paracalliope fluviatilis

OSTRACODA (seed shrimps)

unident. sp.

APPENDIX 8

Sample splitting method

The pond experiments were designed as replicated field experiments, in which each pond was a single replicate. However, inspection of ponds before they were sampled suggested that invertebrate biomass was fairly variable within ponds, and single samples would not necessarily be representative of invertebrates in entire ponds. To estimate the variability of invertebrate biomass within ponds, eight samples were taken from each of 2 ponds. The coefficients of variation for these two sets of eight samples were 0.70 and 0.71. Ideally, replicate samples would be taken within each pond to quantify invertebrate biomass. This was not practical because of time constraints, however. Instead, I decided to take four subsamples from each pond, pool these and then split them in the field (as described in Chapter 8), to yield one representative sample from each pond

The sample splitter consisted of a 40 litre plastic bin mounted on a steel stand (Fig. A8.1). After the subsamples had been mixed, the pooled sample was poured into the 40 litre bin, which was then tilted so that the sample flowed out through four rectangular-sectioned plastic pipes at one end. An even flow through these pipes was ensured by leveling the bin with a small spirit level (fixed to the bin). One quarter of each sample was retained, by collecting the outflow from one of the drainpipes in a 10 litre bucket (Fig. A8.1). If any large detritus or straw became caught in the drainpipes, it was cleared immediately. Any detritus or straw that did not flow out of the drainpipes was spread evenly over the bottom of the bin and halved by eye using a guide line. Half was discarded, and the process repeated to yield a quarter of the detritus, which was placed in the bucket with the rest of the sample.

To be effective, sample pooling and splitting needed to provide more representative (*i.e.* less variable) samples than those provided by taking single samples. I therefore compared the variability of samples obtained by each of these methods. An estimate of within-pond variability was provided by the two sets of eight replicate samples taken from two ponds (see above). To determine the variability of the sample splitting method, I sampled ten ponds using this method. The representativeness of the samples obtained was evaluated by passing pooled subsamples through the splitter and retaining the portion of the subsamples that would normally be discarded,

as well as the 'sample'. Invertebrates in both portions of the sample were then removed, identified, counted, dried at 60° C, weighed to the nearest milligram, and their dry weights compared. This also enabled a check of how many taxa were obtained using this method. The samples for which the method was tested represented a range of substrata and invertebrate densities.

Results of these tests (Table A8.1), confirmed that pooling and splitting subsamples provided a more representative sample from each pond than was provided by taking a single sample. Split samples contained an average of 27% (± 2.1 % SE) of the invertebrate biomass in the pooled subsamples and the coefficient of variation of biomass in the ten tests was 0.25, about a third of that for the two sets of eight replicate samples. An added advantage of pooling and splitting subsamples is that it can be expected to provide a more representative sample of the taxa present in each pond, because 'patchy' invertebrates are more likely to be sampled.

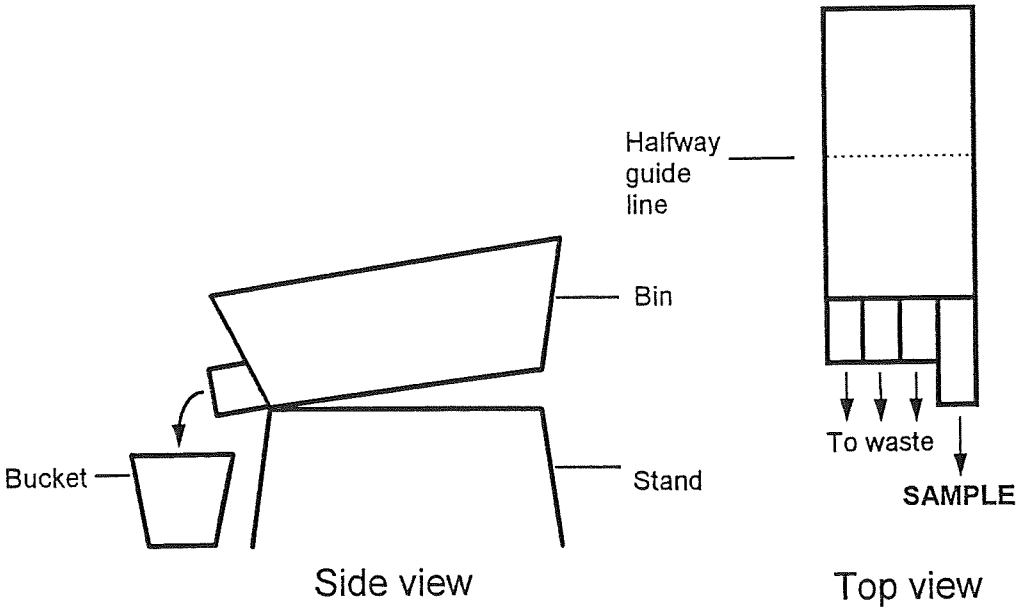


Figure A8.1. Sample splitting apparatus.

Table A8.1. Results of test of sample splitting method. The biomass and number of taxa present in the 'quarter' sample are listed under ¼. The acronyms for substrata follow those in Table 8.2.

Substratum	Pond no.	Biomass (mg per 0.1 m^2)			No. of taxa per sample		
		¼	Total	%	¼	Total	%
BO	17	55	258	21.3	8	16	50
BO	18	66	159	41.5	8	12	67
AF	10	128	411	31.8	5	10	50
AF	11	47	111	27.1	4	5	80
KEB	2	26	121	21.5	5	6	83
KEB	2	17	95	17.9	5	6	83
KEB	2	3	11	27.3	2	3	67
KEB	2	2	8	25.0	1	2	50
MO	11	89	278	32.0	2	4	50
MEB	5	210	823	25.5	7	11	64
Mean				27.09			64.4

APPENDIX 9

Pond experiment data

Table A9.1. Biomass of the four food types recognised in the large-scale substratum manipulation experiment (Chapter 8), in mg dry mass per 0.1 m^2 sample. Substrate acronyms are defined in Table 8.2.

Site	Substrate	Pond no.	Pond age (months)	Oligochaeta	Chironomidae	Nekton	Hard shelled	Total
Tekapo Delta	TO	26	3	121	0	0	1	122
	TO	27	3	42	0	0	0	42
	TO	28	3	80	0	2	0	82
	TO	29	3	44	0	0	0	44
	TO	30	3	192	0	0	0	192
	TRB	1	3	0	18	1	0	19
	TRB	8	3	24	1	37	11	73
	TRB	9	3	0	1	1	11	13
	TRB	12	3	84	1	0	0	85
	TRB	14	3	0	4	3	9	16
	TEM	3	3	190	118	0	0	308
	TEM	4	3	43	50	0	0	93
	TEM	5	3	40	45	1	0	86
	TEM	10	3	37	0	0	0	37
	TEM	11	3	92	6	3	0	101
	TFM	21	3	37	0	18	4	59
	TFM	22	3	32	0	22	4	58
	TFM	23	3	25	0	0	0	25
	TFM	24	3	81	2	1	0	84
	TFM	25	3	36	7	0	0	43
	TR	6	3	0	0	54	0	54
	TR	7	3	3	10	9	0	22
	TR	2	3	0	4	0	0	4
	TR	15	3	4	2	4	0	10
	TR	13	3	6	0	1	0	7
	TFS	16	3	150	0	61	3	214
	TFS	17	3	131	1	14	11	157
	TFS	18	3	37	1	12	4	54
	TFS	19	3	92	0	1	17	110
	TFS	20	3	45	4	16	3	68
Aviary Wetland	AO	1	15	108	2	35	55	200
	AO	6	15	1	6	17	18	42
	AO	8	15	16	7	13	3	39
	AO	17	15	77	2	22	10	111
	AO	21	15	52	1	4	17	74
	AF	2	15	1	0	28	67	96
	AF	4	15	88	0	47	135	270
	AF	9	15	480	13	77	41	611
	AF	10	15	284	4	47	19	354
	AF	11	15	105	1	5	0	111
	AFB	3	15	37	1	82	124	244
	AFB	5	15	31	0	123	24	178
	AFB	18	15	140	2	178	79	399
	AFB	20	15	110	1	137	36	284
	AFS	7	15	1	4	8	2	15
	AFS	12	15	77	127	20	0	224
	AFS	13	15	34	2	62	0	98
	AFS	19	15	16	73	27	0	116
Irishman's Ponds	IO	16	3	43	6	19	33	101
	IO	17	3	134	4	25	99	262
	IO	18	3	59	4	12	190	265
	IO	19	3	2	0	169	97	268
	IO	20	3	20	0	59	86	165

Table A9.1. continued.

Site	Substrate	Pond no.	Pond age (months)	Oligochaeta	Chironomidae	Nekton	Hard shelled	Total
Irishman's Ponds	IE	2	3	0	2	0	0	2
	IE	5	3	1	0	0	0	1
	IE	7	3	0	15	0	0	15
	IE	11	3	0	2	7	19	28
	IE	14	3	0	8	66	8	82
	IE	15	3	0	11	11	1	23
	IER	4	3	0	6	0	8	14
	IER	8	3	1	6	0	0	7
	IER	9	3	0	1	12	0	13
	IER	12	3	0	4	0	0	4
	IEB	1	3	0	4	9	3	16
	IEB	3	3	0	5	5	0	10
	IEB	6	3	4	237	17	8	266
	IEB	10	3	2	12	12	7	33
	IEB	13	3	0	11	5	7	23
Kevin's Diversion	KE	1	3	2	36	0	0	38
	KE	3	3	9	68	42	0	119
	KE	7	3	0	64	47	0	111
	KE	9	3	0	37	22	0	59
	KE	11	3	0	76	32	0	108
	KF	16	3	25	19	6	0	50
	KF	17	3	9	130	92	4	235
	KF	18	3	7	56	22	0	85
	KF	19	3	2	54	26	0	82
	KF	20	3	8	58	30	4	100
	KEB	2	3	1	38	20	1	60
	KEB	6	3	1	14	14	0	29
	KEB	8	3	1	34	75	0	110
	KEB	10	3	0	37	16	1	54
	KEB	12	3	0	120	39	17	176
	KES	4	3	0	2	13	0	15
	KES	5	3	3	67	22	0	92
	KES	13	3	0	18	70	0	88
	KES	14	3	1	29	7	2	39
	KES	15	3	0	14	22	0	36
	KE	1	15	2	0	38	39	79
	KE	3	15	3	2	45	10	60
	KE	7	15	1	2	58	14	75
	KE	9	15	1	5	50	11	67
	KE	11	15	3	6	80	10	99
	KF	16	15	154	2	107	111	374
	KF	17	15	52	0	49	24	125
	KF	18	15	6	2	17	10	35
	KF	19	15	21	0	71	20	112
	KF	20	15	102	4	64	30	200
	KEB	2	15	3	0	107	45	155
	KEB	6	15	2	7	101	69	179
	KEB	8	15	0	6	149	125	280
	KEB	10	15	3	19	302	80	404
	KEB	12	15	4	1	184	39	228
	KES	4	15	3	2	93	7	105
	KES	5	15	2	0	82	9	93
	KES	13	15	0	2	70	9	81
	KES	14	15	0	6	75	7	88
	KES	15	15	1	2	97	4	104
Ben Ohau Seepages	BEB	4	3	53	241	22	4	321
	BEB	6	3	22	236	14	0	272
	BEB	9	3	168	465	71	1	706
	BEB	11	3	133	482	42	1	658
	BEB	13	3	10	69	5	0	85

Table A9.1. continued.

Site	Substrate	Pond no.	Pond age (months)	Oligochaeta	Chironomidae	Nekton	Hard shelled	Total
Ben Ohau Seepages	BES	1	3	48	4	19	1	73
	BES	2	3	75	85	1	0	162
	BES	3	3	25	17	1	0	44
	BES	5	3	8	19	1	0	29
	BES	7	3	4	33	0	0	38
	BE	8	3	88	185	6	4	284
	BE	10	3	159	285	15	0	460
	BE	12	3	34	120	5	0	160
	BE	14	3	7	135	10	0	153
	BE	15	3	14	32	0	0	47
	BO	16	3	53	0	19	4	76
	BO	17	3	39	0	47	32	118
	BO	18	3	38	3	37	50	129
	BO	19	3	16	3	34	36	90
	BO	20	3	310	8	20	48	387
Ben Ohau Seepages	BEB	4	15	4	65	25	11	105
	BEB	6	15	12	38	40	0	90
	BEB	9	15	21	150	31	6	208
	BEB	11	15	25	35	23	0	83
	BEB	13	15	140	3	15	0	158
	BES	1	15	1	1	31	3	36
	BES	2	15	15	0	22	39	76
	BES	3	15	5	0	33	9	47
	BES	5	15	23	0	12	11	46
	BES	7	15	23	0	36	19	78
	BE	8	15	26	0	33	1	60
	BE	10	15	130	0	40	0	170
	BE	12	15	74	13	34	0	121
	BE	14	15	144	0	20	0	164
	BE	15	15	63	9	9	1	82
	BO	16	15	66	0	12	25	103
	BO	17	15	192	0	33	33	258
	BO	18	15	119	1	16	23	159
	BO	19	15	103	0	2	7	112
	BO	20	15	32	3	21	50	106
Mick's Lagoon	MO	11	3	52	0	9	42	103
	MO	12	3	209	0	26	0	235
	MO	13	3	150	0	14	69	233
	MO	14	3	101	0	6	11	118
	MO	15	3	119	0	55	0	174
	MEB	1	3	50	93.5	92	0	235
	MEB	2	3	11	200.9	59	0	271
	MEB	5	3	20	140.8	55	0	216
	MEB	6	3	M	M	M	M	M
	MEB	7	3	M	M	M	M	M
	ME	4	3	139	541	86	0	766
	ME	3	3	9	85	19	0	113
	ME	8	3	62	51	2	0	115
	ME	9	3	89	331	65	0	485
	ME	10	3	121	77	49	0	247
	MO	11	15	274	0	4	0	278
	MO	12	15	616	0	0	2	618
	MO	13	15	324	0	61	0	385
	MO	14	15	440	0	25	0	465
	MO	15	15	48	0	65	0	113
	MEB	1	15	87	5	30	0	122
	MEB	2	15	3	552	53	0	608
	MEB	5	15	639	86	98	0	823
	MEB	6	15	491	306	101	0	898
	MEB	7	15	248	33	4	0	285
	ME	4	15	75	8	165	40	288
	ME	3	15	671	462	65	0	1198
	ME	8	15	203	3	2	2	210
	ME	9	15	520	7	17	6	550
	ME	10	15	800	46	6	0	852

APPENDIX 10

Mick's Lagoon patch experiment data

Table A10.1. Numbers, biomass and taxonomic richness in samples taken from Mick's Lagoon on 31 January 1995 (see Chapter 9 for details). DS = disturbed + barley straw; US = undisturbed + barley straw; D = disturbed, no barley straw; U = undisturbed, no barley straw. Taxa are listed in order of abundance; most abundant taxa are at the top. The number in parentheses after 'number of taxa' is the total number of taxa present in the seven replicates of each treatment. The four food types recognised in the patch experiment (Oligochaeta, Chironomidae, Nekton and Hard-shelled invertebrates) are defined in Chapter 8. Refer to Appendix 7 for full details of taxonomic affliations (Classes, Orders, Families). Note that biomass is presented in mg per 0.1 m^2 sample.

Abundance									
Taxon	DS1	DS2	DS3	DS4	DS5	DS6	DS7	Mean	SE
Oligochaeta	179	421	789	382	499	273	1328	553.00	148.34
Sphaerium novaezelandiae	27	4	36	273	205	167	422	162.00	57.91
Physa acuta	98	99	90	129	126	102	53	99.57	9.55
Potamopyrgus antipodarum	0	0	0	3	12	0	0	2.14	1.70
Lymnaea tomentosa	1	7	1	14	14	5	41	11.86	5.27
Anisops sp.	16	7	23	1	7	5	12	10.14	2.82
Sigara sp.	9	4	2	7	2	13	2	5.57	1.62
Chironomus zealandicus	44	3	30	1	1	4	14	13.86	6.39
Berosus sp.	1	1	0	4	4	6	12	4.00	1.56
Tanypodinae	4	0	5	1	2	4	0	2.29	0.78
Gyraulus corinna	1	3	1	5	4	3	0	2.43	0.69
Xanthocnemis zealandica	0	0	0	3	0	3	2	1.14	0.55
Glossiphonia sp.	2	1	0	1	0	2	2	1.14	0.34
Hygraula nitens	0	0	0	4	0	0	0	0.57	0.57
Ceratopogonidae	0	1	0	0	0	1	0	0.29	0.18
Rhantus pulverosus	0	1	0	0	1	0	0	0.29	0.18
Liodessus sp.	0	0	0	1	1	0	0	0.29	0.18
Hydrachna maramauensis	0	0	0	1	0	0	0	0.14	0.14
Antiporus strigosulus	0	0	0	0	0	0	0	0.00	0.00
Microvelia macgregori	0	0	0	1	0	0	0	0.14	0.14
Oxyethira albiceps	0	0	0	0	0	0	0	0.00	0.00
Paroxyethira hendersoni	0	0	0	0	0	0	0	0.00	0.00
Hudsonema amabilis	0	0	0	0	0	0	0	0.00	0.00
Number of taxa (19)	11	12	9	17	13	13	10	12.14	0.99
Biomass in mg/0.1m2									
OLIGOCHAETA	119	196	557	173	254	100	459	265.43	66.33
CHIRONOMIDAE	11	1	12	0	0	5	6	5.00	1.90
NEKTON	62	39	49	29	25	58	38	42.86	5.31
HARDSHELLED	40	40	63	95	102	99	166	86.43	16.67
TOTAL	232	276	681	297	381	262	669	399.71	73.18

Table A10.1. continued.

Abundance									
Taxon	US1	US2	US3	US4	US5	US6	US7	Mean	SE
Oligochaeta	351	241	204	99	62	272	265	213.43	38.39
Sphaerium novaezelandiae	104	85	190	155	63	86	86	109.86	17.21
Physa acuta	71	44	201	41	29	46	61	70.43	22.37
Potamopyrgus antipodarum	0	1	0	0	0	0	1	0.29	0.18
Lymnaea tomentosa	3	14	10	9	2	6	8	7.43	1.57
Anisops sp.	12	15	17	10	29	2	3	12.57	3.47
Sigara sp.	7	19	17	13	11	15	6	12.57	1.85
Chironomus zealandicus	3	5	7	2	0	1	0	2.57	1.00
Berosus sp.	2	5	2	6	1	2	1	2.71	0.75
Tanypodinae	2	4	3	5	0	1	1	2.29	0.68
Gyraulus corinna	0	0	3	0	1	0	1	0.71	0.42
Xanthocnemis zealandica	1	3	1	0	1	6	2	2.00	0.76
Glossiphonia sp.	0	1	2	1	2	0	0	0.86	0.34
Hygraula nitens	1	0	0	0	0	1	0	0.29	0.18
Ceratopogonidae	2	0	0	0	0	0	0	0.29	0.29
Rhantus pulverosus	0	0	0	0	1	1	0	0.29	0.18
Liodessus sp.	0	0	0	0	0	0	0	0.00	0.00
Hydrachna maramauensis	1	0	1	0	0	0	0	0.29	0.18
Antiporus strigosulus	0	0	0	0	0	0	0	0.00	0.00
Microvelia macgregori	0	0	0	0	0	0	0	0.00	0.00
Oxyethira albiceps	1	0	0	0	0	0	0	0.14	0.14
Paroxyethira hendersoni	0	0	0	0	0	0	0	0.00	0.00
Hudsonema amabilis	0	0	0	0	0	0	0	0.00	0.00
Number of taxa (18)	14	12	13	10	11	12	11	11.86	0.51
Biomass in mg/0.1m2									
OLIGOCHAETA	104	96	52	46	24	84	70	68.00	10.93
CHIRONOMIDAE	1	1	2	2	2	0	0	1.14	0.34
NEKTON	47	121	88	55	90	48	27	68.00	12.33
HARDSHELLED	56	80	124	83	50	32	60	69.29	11.26
TOTAL	208	298	266	186	166	164	157	206.43	20.83

Table A10.1. continued.

Abundance									
Taxon	D1	D2	D3	D4	D5	D6	D7	Mean	SE
Oligochaeta	161	76	116	188	177	126	125	138.43	14.79
Sphaerium novaezelandiae	220	45	12	86	111	109	114	99.57	24.77
Physa acuta	34	0	0	12	18	3	3	10.00	4.74
Potamopyrgus antipodarum	152	11	1	66	0	1	0	33.00	21.80
Lymnaea tomentosa	13	0	0	3	11	3	1	4.43	2.02
Anisops sp.	1	0	1	0	0	1	4	1.00	0.53
Sigara sp.	1	3	0	0	3	2	2	1.57	0.48
Chironomus zealandicus	3	3	2	0	3	1	3	2.14	0.46
Berosus sp.	9	3	7	6	1	0	1	3.86	1.32
Tanypodinae	0	2	0	0	3	4	5	2.00	0.79
Gyraulus corinna	0	0	1	0	4	0	0	0.71	0.57
Xanthocnemis zealandica	0	0	0	0	0	0	0	0.00	0.00
Glossiphonia sp.	0	0	0	0	0	0	0	0.00	0.00
Hygraula nitens	0	1	0	1	0	0	0	0.29	0.18
Ceratopogonidae	0	0	0	0	0	0	0	0.00	0.00
Rhantus pulverosus	1	0	0	0	0	0	0	0.14	0.14
Liodessus sp.	0	1	0	0	0	0	0	0.14	0.14
Hydrachna maramauensis	0	0	0	0	0	0	0	0.00	0.00
Antiporus strigosulus	0	0	0	0	2	0	0	0.29	0.29
Microvelia macgregori	0	0	0	0	0	0	0	0.00	0.00
Oxyethira albiceps	0	0	0	0	0	0	0	0.00	0.00
Paroxyethira hendersoni	1	0	0	0	0	0	0	0.14	0.14
Hudsonema amabilis	0	0	0	1	0	0	0	0.14	0.14
Number of taxa (17)	11	9	7	8	10	9	9	9	0.49
Biomass in mg/0.1m2									
OLIGOCHAETA	70	44	51	83	96	62	53	65.57	7.07
CHIRONOMIDAE	1	1	0	0	1	3	1	1.00	0.38
NEKTON	22	14	16	10	13	9	18	14.57	1.72
HARDSHELLED	102	15	2	45	21	19	8	30.29	13.00
TOTAL	195	74	69	138	131	93	80	111.43	17.32

Table A10.1. continued.

Abundance									
Taxon	U1	U2	U3	U4	U5	U6	U7	Mean	SE
Oligochaeta	382	161	259	104	201	41	128	182.29	42.43
Sphaerium novaezelandiae	68	79	121	39	39	18	44	58.29	12.94
Physa acuta	0	0	0	2	1	0	0	0.43	0.30
Potamopyrgus antipodarum	0	0	0	0	0	1	0	0.14	0.14
Lymnaea tomentosa	2	0	7	0	3	1	0	1.86	0.96
Anisops sp.	0	4	0	0	1	0	0	0.71	0.57
Sigara sp.	0	0	0	0	1	0	0	0.14	0.14
Chironomus zealandicus	0	0	0	0	0	0	0	0.00	0.00
Berosus sp.	0	1	0	0	0	0	1	0.29	0.18
Tanypodinae	0	0	0	0	1	0	0	0.14	0.14
Gyraulus corinna	0	0	0	0	0	0	0	0.00	0.00
Xanthocnemis zealandica	0	0	0	0	0	0	0	0.00	0.00
Glossiphonia sp.	0	0	0	0	2	0	0	0.29	0.29
Hygraula nitens	0	0	0	0	0	0	0	0.00	0.00
Ceratopogonidae	1	0	1	0	0	0	0	0.29	0.18
Rhantus pulverosus	0	0	0	0	0	0	0	0.00	0.00
Liodessus sp.	0	0	0	0	0	0	0	0.00	0.00
Hydrachna maramauensis	0	0	0	0	0	0	0	0.00	0.00
Antiporus strigosulus	0	0	0	0	0	0	0	0.00	0.00
Microvelia macgregori	0	0	0	0	0	0	0	0.00	0.00
Oxyethira albiceps	0	0	0	0	0	0	0	0.00	0.00
Paroxyethira hendersoni	0	0	0	0	0	0	0	0.00	0.00
Hudsonema amabilis	0	0	0	0	0	0	0	0.00	0.00
Number of taxa (11)	4	4	4	3	8	4	3	4.29	0.64
Biomass in mg/0.1m2									
OLIGOCHAETA	111	53	67	32	63	14	31	53.00	12.06
CHIRONOMIDAE	0	0	0	0	0	0	0	0.00	0.00
NEKTON	0	6	0	0	8	0	0	2.00	1.31
HARDSHELLED	8	4	16	8	6	2	3	6.71	1.78
TOTAL	119	63	83	40	77	16	34	61.71	13.18